Official Transcript of Proceedings

NUCLEAR REGULATORY COMMISSION

OPEN: RES Brunswick ATWS-Instability Confirmatory Analysis
Transcript with Slides

Title: ACRS Thermal-Hydraulic Subcommittee - Open Session

Docket Number: N/A

Location: Rockville, Maryland

Date: May 15, 2018

Work Order No.: NRC-3730 Pages 1-199

NEAL R. GROSS AND CO., INC.
Court Reporters and Transcribers
1323 Rhode Island Avenue, N.W.
Washington, D.C. 20005
(202) 234-4433

DISCLAIMER

UNITED STATES NUCLEAR REGULATORY COMMISSION'S
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

The contents of this transcript of the proceeding of the United States Nuclear Regulatory Commission Advisory Committee on Reactor Safeguards, as reported herein, is a record of the discussions recorded at the meeting.

This transcript has not been reviewed, corrected, and edited, and it may contain inaccuracies.

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

+ + + + +

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

+ + + + +

THERMAL-HYDRAULIC SUBCOMMITTEE

+ + + + +

OPEN SESSION

+ + + + +

TUESDAY

MAY 15, 2018

+ + + + +

ROCKVILLE, MARYLAND

+ + + + +

The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11545 Rockville Pike, at 8:30 a.m., Jose A. March-Leuba, Chairman, presiding.

COMMITTEE MEMBERS:

JOSE A. MARCH-LEUBA, Chairman

MICHAEL L. CORRADINI, Member

JOY L. REMPE, Member

DESIGNATED FEDERAL OFFICIAL:

ZENA ABDULLAHI

ALSO PRESENT:

JOSHUA BORROMEO, NRR

MICHAEL CASE, RES

JOSEPH L. STAUDENMEIER, RES

PETER YARSKY, RES

STEPHEN YODERSMITH, Duke Energy

*Present via telephone

TABLE OF CONTENTS

P R O C E E D I N G S

8:29 a.m.

CHAIRMAN MARCH-LEUBA: This is a meeting of the Thermal-Hydraulic Subcommittee of the Advisory Committee on Reactor Safeguards. I am Jose March-Leuba, subcommittee chairman. ACRS members in attendance today are Mike Corradini and Joy Rempe. Zena Abullahi is the federal official for this meeting.

Today, the Office of Research staff will brief us on the ATWS-instability/TRACE confirmatory analysis. In the past, the Office of Research staff has briefed us on the Kathy test program to establish the minimum film boiling temperature or Tmin for ATWS-instability event. Included in this brief is what Tmin will be used for MELLA+ analysis.

We have one bridgeline arranged for interested members of the public to listen in during the open portion of the meeting. In order to minimize noise, this line will be kept in mute. At the end of the open portion of the meeting, we will request if anyone listening would like to make any comments. We have received no written comments or requests for any time to make oral statements from members of the public regarding today's meeting. This agenda shows when the meeting will be open or closed. A separate closed bridge number is available for staff. Please place your phones in mute to minimize interference. Also, state your name, the organization you represent before we commence the closed portion of the meeting. I request Research staff to confirm that a participant on the staff line or members of the staff are cleared to participate.

As the meeting is being transcribed, I request all participants use the microphones located throughout this room when addressing the subcommittee. Participants should first identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

Let me remind you to please ensure that all devices have been placed in silent mode to minimize disturbances during the meeting. We will now proceed with the meeting, and I call on Mike Case to provide us with a short introduction on the top.

MR. CASE: Sure. Thanks. Good morning, everyone. My name is Mike Case. I'm the director of the Division of Safety Analysis in the Office of Research. Thanks for your technical insights that you'll provide at this meeting. They're really valuable to us to make sure that we have, you know, not just a quality product here but a quality product in the future, so we appreciate that.

Some things to keep in mind. We're actually not the star of this show. You know, we're doing this for our friends in NRR. They're doing a safety review, and so they're really the stars of the show. We're trying to be the best supporting actors and actresses. So we're doing a confirmatory analysis to really support their safety conclusions, so you'll hear more from them I think tomorrow.

This was a really challenging calculation for us. The codes probably weren't behaving as well as we would hope they would be, so we put a lot of folks on this and they did a lot of really good hard work. And so Pete is representing the results, but there's a bunch of people over in the back that all worked, at times weekends, in order to make this come to fruition. So we really appreciate the hard work that our staff put in to do this.

The one last thing to remember is this is not the last time we'll do this calculation, so there is another MELLA+ review coming up. So when you think about comments that you make, you know, sometimes, certainly we want this product to be technically sound, but sometimes we may listen to the comments and apply them towards the future, rather than try and re-do the past.

So with that, I think I can turn it over to Dr. Yarsky.

CHAIRMAN MARCH-LEUBA: Not the PC. Our primary concern here is the technical calculations and the technical process, but on another aspect or facet of ACRS, we review research, we're in charge of review of research products. And maybe while he's working, you can think about giving us a couple of minutes' tutorial how this interaction with NRR and NRO works with you. How well does it work? How can it be improved maybe? How does the use of it work out?

We're willing to learn more about your insights on how this can be improved because one concern we hear often is it takes, obviously, are very hard and very difficult. It takes too long to get feedback for the licensing process.

MR. CASE: Well, I can react right now. That's probably true, and so some of it is, you know, bringing the lessons learned forward. I think the interaction is okay. You know, I don't think there's things that we can do to sort of get us out in front of the amendment itself. So a lot of it is tied to the initiation of the amendment, and so we would like to have more time doing these things, but I don't know a way around that yet. Some of that, you know, we're thinking about that more in the context of ATF. In other words, how can we start to get information early so that we can prepare the code so that when the amendment comes? Instead of us starting then, it's really we start with the calculation itself, not with preparing to do the calculation.

CHAIRMAN MARCH-LEUBA: Yes. And another thing you have control over is the availability of key staff because whenever a new project comes everybody wants Peter, and Peter is already doing 12 things. So we need to plan ahead or something, you know. The availability of key staff and having them ready to go is key to timeliness.

MR. CASE: And some of the other things we're doing in user-need space is, from NRR, they asked us to start to put together, you know, decks that can be used. So that's sort of preparing ahead, instead of waiting for the amendment and say, okay, I need to do a deck now. So we're thinking of how to do it better.

CHAIRMAN MARCH-LEUBA: Okay.

MEMBER REMPE: So along those lines, for the next MELLA+ is it also a BWR4 or what will the next MELLA+ and do you have a deck ready to go for it?

MR. CASE: It's Browns Ferry and we're working on it.

MEMBER CORRADINI: Maybe Peter is going to get into this, and so you can hold us off. I'm trying to figure out what requires it to be specific versus generic? Is it the operator actions? Is it detail core design? Is it --

DR. YARSKY: I have a slide on that that specifically addresses that question of what are the specific aspects of any given plant that warrant a plant-specific evaluation.

MEMBER CORRADINI: Okay, fine.

CHAIRMAN MARCH-LEUBA: Maybe you have a generic deck. Can you change the production from 90 to 120 or --

DR. YARSKY: We currently have a project to do that that we're working on in research right now. But, again, with resources, that's been a lower priority than doing this Brunswick plant-specific.

CHAIRMAN MARCH-LEUBA: Let's wait for your slide.

DR. YARSKY: Okay.

CHAIRMAN MARCH-LEUBA: So go ahead.

DR. YARSKY: Thank you. I'm Dr. Peter

Yarsky from the Office of Research, and I'll be giving this presentation on our confirmatory analysis of AWTS with instability for the Brunswick MELLA+.

First, I would like to go over a short overview of ATWS with instability in the context of MELLA+. After that, we'll talk about the NRC's analysis methodology, then differences between the units at Brunswick. Then we'll go through our reference ATWS-I scenario and then a series of sensitivity studies that we've conducted. At the end, we'll go into closed session where we'll give a presentation comparing the research staff's analysis results to those submitted by the licensee and wrap up with conclusions.

So, first, the Office of Research was tasked by NRR to conduct confirmatory analyses for Brunswick for anticipated transients without SCRAM with instability as part of their review of the MELLA+ license amendment. In research, we used our suite of codes to perform the confirmatory analysis and we'll be presenting the results for our base case, as well as high-priority sensitivity cases.

At the conclusion, we'll talk about the comparison between the research's TRACE/PARCS results and those that were submitted by the licensee. The licensee's calculations were performed with TRACG. And some portions of the presentation will have to be closed due to that discussion of proprietary information.

CHAIRMAN MARCH-LEUBA: So as you talk about it, because I'm curious, do you use PATHS?

DR. YARSKY: Yes.

CHAIRMAN MARCH-LEUBA: Too establish the steady state of --

DR. YARSKY: I have a slide on that. We use PATHS pretty extensively.

CHAIRMAN MARCH-LEUBA: Okay. I'm glad you're doing it now because we didn't used to.

DR. YARSKY: Yes, it's certainly a higher quality of life now that we have PATHS available to fill in certain steps in our methodology.

So next, I'd just like to give a brief overview. This is material that's been presented to the subcommittee before, so I'm hoping to go through it in a rapid, brisk pace in an abbreviated manner.

So the MELLA+ domain, as I'm sure we're quite familiar, represents an expansion of the operating domain that allows operation at EPU power levels but at low core flow rates. So you can think 120 percent of originally licensed thermal power and perhaps as low as 80 percent of rated core flow rate. And operating at this condition introduces new aspects to the progression of postulated anticipated transients without SCRAM. The safety significance of this is, essentially, operating at a lower core flow rate means that the dual recirculation pump trip is less effective in mitigating events that normally would be mitigated with a dual recirculation pump trip.

If we show this on power flow operating domain map and we consider an event initiated from originally-licensed thermal power rated core flow, an ATWS event, the trajectory shows the power decreasing in response to the dual recirculation pump trip and then increasing due to the injection of cold feedwater. And this evolves to a condition of relatively high-powered flow ratio. However, that same event initiated from the MELLA+ corner evolves to a higher power level at lower flow and potentially much more unstable condition.

So we can compare these points where the plant will evolve following dual recirculation pump trip and considering originally-licensed thermal power or EPU or then MELLA+, the tendency is for the plant to evolve conditions that are increasingly more unstable.

So the overview of a typical anticipated transient without SCRAM with instability event is consideration of a turbine trip with turbine bypass capability.

MEMBER CORRADINI: So I know you've told us this before, but I don't remember. You kind of switch from reactor pump trip to turbine bypass. It's not clear which one is limiting with any particular design or particular specific reactor; is that correct?

DR. YARSKY: Yes. So the turbine trip is what we postulate as the initiating event. I mean, ATWS can be initiated by any number of events. But the turbine trip tends to be limiting because it will isolate extractions in the feedwater heater cascade. So that's what I was showing here. There's two pieces here. There's the flow reduction from the dual recirculation pump trip, and that occurs because of the turbine trip. Then there's this increase in power from the reduction in temperature.

MEMBER CORRADINI: But if I had a 2RPT alone without a turbine trip --

DR. YARSKY: You can still get into --

MEMBER CORRADINI: But it would be --

DR. YARSKY: -- a potentially unstable, yes, there would be some differences there.

CHAIRMAN MARCH-LEUBA: But the confusion, while you remember the difference, is with operator actions. When the turbine trip happens, it triggers the 90-second or 120-second operator action establishing water level, and the operators can be so good that the oscillations never happen with a turbine trip, whereas in a recirculation pump trip there's no immediate operator action. You have to wait until instability happens and then the operators take action.

So in some circumstances, a turbine trip never shows instability and recirculation pump trip never shows instability. But that's when you factor the operators in it. And if you take operators off, turbine trip is much worse, absolutely no contest.

DR. YARSKY: But I did want to mention, and we'll talk about this again later in the presentation, is that with turbine bypass capacity differences, this essentially will have an impact on average RPV pressure during the event if turbine bypass is available, if you have a high turbine bypass capacity or a low turbine bypass capacity. This is an important aspect to take into account in the analysis of the event, but it has a bit of a competing effect in terms of the overall event progression. And we can talk about that more when we get to that slide.

So we talked about the event being initiated by turbine trip, and this is sort of the reference event is turbine trip with bypass available. The turbine trip will result in a pressure pulse, the dual recirculation pump trip, loss of extraction steam, and then this is what will lead the core to evolve into an unstable condition where large amplitude, power and flow oscillations are possible. The event is eventually mitigated by operator actions to lower reactor water level and to inject boron through the standby liquid control system.

Previously, the staff had done studies on a generic BWR plant to look at the consequences of postulated ATWS with instability. In the conduct of that work, we identified a mechanism for fuel heat-up from our TRACE predictions that indicated it would be possible for large-amplitude oscillations to cause the fuel to first go through a phase of periodic dryout and rewet, so that during the oscillation there would be a short span of that period where the fuel would be in dryout but then it would subsequently rewet.

And as the magnitude of these oscillations continue to grow and, in particular, the flow oscillation, that amount of time it spent in dryout would just get like a little bit more and then eventually the rewet part of the oscillation was not sufficient to remove all of the energy that builds up during the dryout part. And this would cause the temperature in the fuel elements to ratchet upwards.

Eventually, as a function of this ratcheting of the temperature, the surface temperature would exceed the minimum stable film boiling temperature and then the cladding surface would lock into film-boiling heat-transfer regime and then this would cause the fuel to undergo a significant fuel heatup.

When analyzing any specific application for MELLA+ and doing an ATWS-I analysis, there are important aspects to the plant design that need to be considered in that calculation, and these can all impact the prediction of fuel consequences. This includes the fuel and the core design, the turbine bypass capacity, the manual operator action timing, the SLCS boron enrichment, the design of the feedwater pumps and in particular whether or not they're motor or steam driven, the feedwater temperature transient that occurs following the isolation of extraction scheme, and whether or not the plant has any automated protective features that would be actuated during an ATWS and, in particular, just talking about Nine Mile Point 2, which is a bit of an unusual plant with respect to this.

CHAIRMAN MARCH-LEUBA: For the record, unusually good.

DR. YARSKY: Yes, unusually good but it's atypical.

MEMBER CORRADINI: So those are the plant-specific considerations, but what drives you to do a plant-specific calculation versus the licensee showing you their approach and you just essentially auditing or analyzing that? Why do a TRACE/PARCS calculation?

DR. YARSKY: Well, I think the purpose of confirmatory analysis in general is not to replace the licensing basis for the plant or the application but, rather, to assist NRR In conducting its review. So looking at our analysis results can guide the NRR review to say, you know, hey, in areas where the analyses agree, maybe we don't need to ask as many questions about that aspect of the licensee's analysis. And if there are areas of disagreement --

MEMBER REMPE: In this particular case, they had AREVA fuel and so they had to rely on AREVA methods for some aspect and GE methods for other aspects. And so I thought it was very helpful of -- it was a good idea.

MEMBER CORRADINI: That was the particular case. So prior to this, I don't remember us doing a scene of plant-specific. Was that the reason here, the sole reason?

DR. YARSKY: I don't know if I would say that was the sole reason, but I could direct this question to NRR in terms of the motivation for requesting the confirmatory analysis.

CHAIRMAN MARCH-LEUBA: Would you say the primary reason was that now you could do it and before you couldn't? I mean, you would have to take --

DR. YARSKY: Our methods have certainly evolved. There was a period of time during which there were applications for, like under review for MELLA+ before the NRC's confirmatory analysis methods were mature enough to do this kind of calculation.

CHAIRMAN MARCH-LEUBA: When you say plant-specific TRACE model from scratch, from zero, it's a monumentous effort? You can't do it in two weeks?

DR. YARSKY: Right, right. It is a significant amount of effort.

CHAIRMAN MARCH-LEUBA: Yes. So that's the problem. When you have to do a confirmatory, you have an 18-month cycle that you have to respond to. And if you don't have the model ahead of time, you cannot do it.

MEMBER CORRADINI: So is NRR going to answer that?

MR. BORROMEO: Yes. This is Josh Borromeo from NRR. So, you know, particularly in this case, it was helpful because of the AREVA and GE, the mixing and matching of methods and fuel. But because the methods, research's methods are becoming more mature, we are hoping to gain efficiency with our review. So possibly asking RAIs and being able to crank through our review a little bit quicker.

MEMBER CORRADINI: Okay. That makes sense then. So when you do this, is your intent to look at the boundaries of where there's a cliff or a major change, rather than replicate exactly what they're doing? Because, in some sense, you can ask a couple of questions and get a clear picture whether or not their behavior with all of these attributes. But the only reason I'm asking that is you and what you're eventually going to get to show us something in closed session that made me think you were trying to find where there was a bound in terms of behavior.

CHAIRMAN MARCH-LEUBA: Your sensitivity analysis.

DR. YARSKY: Yes, we conducted a significant body of sensitivity analyses. One of those is to address the current shortcoming of our method, and that's with regards to the gap conductance. The other sensitivities that we looked at in regards to operator action timing, for example, was to compare against analyses that had been supplied by the licensee. And there's another body of sensitivity calculations that we did that we're not presenting on today that looked at different aspects that are unique to the methodology of analysis that was done by Brunswick, not to put too fine a point on it. Maybe we can talk about it in closed session.

MEMBER CORRADINI: Okay. That helps me.

DR. YARSKY: But if we were to, in our analysis methodology, we didn't specifically try to look for any kind of, like, crossover points.

CHAIRMAN MARCH-LEUBA: Yes, let me put a plug for my favorite topic, which I typically use in risk analysis meetings, but it can be applied to transient analysis, too. And I call it uncertainties of omission. You guys have been hearing from me all the time is what did you forget to account for in your analysis? So by doing this confirmatory analysis, in my opinion, the primary value of it is doing the calculation completely independent with different brains and different experiences and maybe you find some place where this diverges. And the key example is, I know I was working with you or for you at the time, is when we discovered the Tmin issue.

DR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: If we have not, the staff had not been doing the confirmatory calculations with TRACE, we would be calculating the Tmin all the way and saying there's absolutely no consequences to this, and it was through this confirmatory calculation saying, hey, we're getting a completely different number than you are. And we got together, we did all the tests, and I think we are much better now because of that.

MEMBER CORRADINI: We can wait until closed session.

MEMBER REMPE: So out of curiosity, for the Peach Bottom deck, since it's a BWR4 but a much higher power than Brunswick, is it a big effort to come up with another deck? Can you skee off a lot of it, or was it -- it surely must be easier than it was to go from the hodgepodge reactor to Brunswick to go from Brunswick to Peach Bottom, right?

DR. YARSKY: Well, sometimes it depends on what we have in-house from other efforts. So for Brunswick, I don't remember if we were able to start from an existing LOCA deck, but I feel like we may have actually started from a Browns Ferry LOCA deck for the Brunswick work. But part of what we're doing in research, an effort we have is to, for every major plant class, is to sort of take an exemplar from the fleet and then have that in a sort of bank where we maintain it and sort of keep that deck up to date so that if we needed to do an analysis, plant-specific for a similar plant, then it would just be a matter of making that delta.

For BWR4s, I'm pretty sure that our plant is Browns Ferry. But then if there were another BWR4 to come in, our efforts would start with establishing a list of deltas from that example plant.

CHAIRMAN MARCH-LEUBA: So going from management, it's not only the deck but it's the people that can run it and have the sufficient experience to identify mistakes when you make them and correct them. So you can just have a series of decks and then just say go for it.

DR. YARSKY: Well, the other thing that's important is that we're maintaining these as LOCA decks, and those LOCA decks also have to be changed into decks that would be appropriate for an ATWS calculation. There are many changes that need to be made to things like nodalization or including different systems, removing systems. So there's a number of modifications that would need to be made anyway.

MEMBER CORRADINI: So this is kind of -- I know what licensees have to do in terms of data book calculations and verification of input. Now, does the staff do exactly the same thing?

DR. YARSKY: The staff does something that's very similar, but I would not say that we're Appendix B compliant in all cases.

MEMBER CORRADINI: That's not what I'm asking. I'm just asking, from an engineering judgment standpoint, there is a person that develops the calculational input model and there's a second person that checks the calculational input model and signs off on it so that at least two people independently have looked at a calculation, so I understand that the loss factor here is X and somebody say, yes, I checked that loss factor calculation and it should be X?

DR. YARSKY: Right.

MEMBER CORRADINI: Okay. That's all I'm -- I don't want to get into Appendix B. But at least from an engineering action standpoint, that's how applicants have typically done it, developing a calculation and then having a separate entity check that.

DR. YARSKY: Yes, we do that but we're going to be incorporating a new step into our process, which is called like a design review process where you have sort of the analysts that are working on the model doing that peer checking, but then decks for, like, these major plant types will then have to be presented to the senior staff in a series of presentations that we're calling a design review to go through, like, all of the modeling options and choices, nodalization, all of these features in the calculation. So that's another element of the process that's being introduced --

MEMBER CORRADINI: I just want to make sure that it was the general process. That's all.

DR. YARSKY: Okay. So with that, I would like to move on.

CHAIRMAN MARCH-LEUBA: Are we at the point where we're going to do Tmin?

DR. YARSKY: No, we're not at that point yet. We're just going to skip that part.

CHAIRMAN MARCH-LEUBA: But since it's in the agenda, I have to put you on the record that we have decided the closed session that's scheduled from 9:00 to 9:10 on Tmin, we are not going to have it now and really we're not going to have the rest of it because we had a meeting on this last month. So the three of us already know everything. If there's any questions, we can do it in the closed session later on on the calculations.

DR. YARSKY: Well, if we were to do that, we would have to do a separate kind of closed session because the --

CHAIRMAN MARCH-LEUBA: We will drop Tmin. We will not have anything any Tmin issues because, yes, it's a different proprietary issue.

DR. YARSKY: Yes.

CHAIRMAN MARCH-LEUBA: I understand.

DR. YARSKY: Okay. So I'd like to present on the methodology that the research staff used to conduct the confirmatory analysis. And I just sort of want to go through this step by step in terms of what we did. It's a little bit different from what we had previously done, and I would like to highlight along the way the ways that we're able to use PARCS and PATHS together to address aspects of the methodology that were particularly tedious or not fully independent in the past.

So the first step in our analysis method is first to perform steady-state PARCS/PATHS cycle analysis. So this is something that I believe may be the first time we're presenting this to the subcommittee is that we now do an independent cycle exposure calculation so that we independently derive the exposure and exposure history distributions for the reference cycle.

As a first step to this calculation, first we generate the cross-sections. In the current work we used CASMO-5 to generate the cross-sections. You won't be seeing that again in the future because we've developed a methodology called POLARIS that's part of the scale package that we'll be using for cross-section generation in the future, but I'm sure the members are familiar with CASMO-5.

In the second step, we developed the PARCS and PATHS model using the thermal-hydraulic and nuclear design information for the reference core. And, third, we perform an equilibrium cycle search using that PARCS/PATHS model and are then able to converge the equilibrium cycle. So then we now have an independent capability for determining things like the exposure distribution.

CHAIRMAN MARCH-LEUBA: How long does this take? Because it used to take like three years.

DR. YARSKY: So at one point in the past, we used TRACE to drive cycle depletion for Peach Bottom cycle one, which took months and months to run. This kind of calculation, to do a cycle depletion, is something that you would measure it probably in hours. The equilibrium cycle search is longer, of course, because it takes many cycles do you have to run before you converge. So this would be something you may be talking overnight, maybe two nights. Certainly, much, much quicker.

CHAIRMAN MARCH-LEUBA: You would expect that you will do it for every application now.

DR. YARSKY: Yes, all the time. We're going to do this all the time because when we get to the next slide, when we get to the next slide it's the results from PARCS/PATHS to fill in things where we had to drive PARCS in an unusual way in the past. So, first, we can use PARCS/PATHS to independently determine the most limiting point in the cycle, so we can calculate the peak point independently.

MEMBER CORRADINI: So what is PATHS? I'm sorry. I should --

DR. YARSKY: Oh, so PARCS, I'm sure you're more familiar with, is the 3-D kinetics package and it also does, like, the steady state, nuclear design type calculations, but it doesn't have its own BWR-appropriate thermal hydraulic solver until very recently. So PATHS is a simplified thermal-hydraulics solver.

MEMBER CORRADINI: It's a steady-state TRACE or steady-state COBRA?

DR. YARSKY: Think way simpler. You got to go, like, what quality correlation, single fluid.

MEMBER CORRADINI: So it's a homogeneous model for determining neutronics parameters?

DR. YARSKY: Well, you're determining the void distribution, so it's whatever you need to get steady-state void fraction. But you don't have any fancy bells and whistles, so you don't really have like a two fluid interfacial sheer model, you just have like a void quality correlation.

MEMBER CORRADINI: Of some sort.

DR. YARSKY: Right. And we have different options. I mean, we could get into PATHS, but the idea is to have something that can run very quickly and you really only need it to do steady-state void fraction. So it's much simpler in terms of modeling than what's available in TRACE.

CHAIRMAN MARCH-LEUBA: Yes, but if you look at it, the experimental void fraction feeds both the steady-state void quality calculation and the more sophisticated models.

DR. YARSKY: Right. So we have validated PATHS against things like BFBT and we have similar performance for that steady-state data as we would for TRACE. But you couldn't take PATHS and use it to run a LOCA calculation. It would be inappropriate to do that.

MEMBER CORRADINI: You've answered my question. Thank you.

DR. YARSKY: So what we can do now is now that we have the PARCS/PATHS we can do the steady-state calculations to determine the exposure distributions, we can determine the power distributions, determining PCT access point in cycle. What I love is that we can determine the bundle-to-bundle peaking factor, so we have the radial power distribution from the PARCS/PATHS calculation that we can then use to inform a channel grouping to use in the TRACE calculation.

So previous calculations had been able to exploit, to some extent, some symmetry in the core but still resulted in models that would have hundreds and hundreds of TRACE channel components. With the capability to independently calculate the power shape a priori with PARCS/PATHS, we can now determine an appropriate TRACE channel grouping and that allows us to cut down the number of channel groups by, like, a factor of five. So it's a very significant improvement.

CHAIRMAN MARCH-LEUBA: So how many channels are you using?

DR. YARSKY: This particular calculation we're presenting is done with a 42-channel model.

CHAIRMAN MARCH-LEUBA: And you're speaking full core symmetry there, I mean out of phase --

DR. YARSKY: This is still exploiting just the one-half of the core, so we're still doing a -- so this would not permit the rotating mode.

CHAIRMAN MARCH-LEUBA: But it would be permit the out of phase.

DR. YARSKY: But it permits the out of phase. So if you imagine, like, it supports one symmetry line in the out-of-phase mode. Our standard process will relax that, so where we would be talking on the order of 50 channels using this type of methodology, moving forward we're going to double that so we have, like, the quarter cores are separated so we're not taking advantage of that symmetric plane that is perpendicular to the out-of-phase plane.

CHAIRMAN MARCH-LEUBA: Okay.

DR. YARSKY: I hope that makes sense.

CHAIRMAN MARCH-LEUBA: It does.

DR. YARSKY: But there's 42 channels in this calculation. What we can also do is we can also use PARCS/PATHS to calculate the first harmonic shape. This is calculating that out-of-phase mode contour, and that becomes an input into the transient calculation. But now we can do that directly from the PARCS/PATHS calculation. So we can get all of these inputs with what will go into the TRACE model. We can do all of this with the steady-state PARCS/PATHS methodology, so it's a significant improvement to our overall calculation process.

CHAIRMAN MARCH-LEUBA: Are you able to transfer initial conditions from PATHS to PARCS?

DR. YARSKY: No.

CHAIRMAN MARCH-LEUBA: So you still have initial bump?

DR. YARSKY: What?

CHAIRMAN MARCH-LEUBA: You still have initial bump. If you guess wrong --

DR. YARSKY: There's not -- it will still do, like, value offset, but there will be a difference in the void distribution.

CHAIRMAN MARCH-LEUBA: Yes, thermal-hydraulics, if you get close to the solution, sometimes you're very far away from the solution, TRACE can bump too much and --

DR. YARSKY: Yes, we accept that that's -- we don't want to go after that too much with our methodology because we're going to have a distortion no matter what because we would like to exploit channel grouping. So what we do is we incorporate a step where we compare the power distribution from the TRACE/PARCS coupled calculation back to the PARCS/PATHS calculation and then say those power distributions have to agree within certain tolerances.

But since we're doing channel grouping, we're already introducing some smearing effects that are going to distort the power distribution. So you have that price to pay anyway, so if we were to do something, like put in some kind of offset so that in one-to-one channel grouping we could get them to match exactly, we still wouldn't have that as the end result anyway.

So next I would like to talk about what is a bit of a shortcoming in our current analysis. The research staff, though our mechanical modeling capabilities advanced since the previous MELLA+ work, what I'm particularly referencing is the development of FAST, which replaces FRAPCON and FRAPTRAN. And those same detail models are available now in TRACE, so TRACE is a more sophisticated thermal-mechanical analysis capability today than we previously had.

However, a number of the --

MEMBER CORRADINI: So if you could just slow down a minute, so are you telling me that FRAPCON and FRAPTRAN are now inside of TRACE or somehow linked? Is that what you just said?

DR. YARSKY: No, I don't want to say that. What I want to say is the capabilities that we formally had with FRAPCON and FRAPTRAN will be replacing with a new methodology called FAST.

MEMBER CORRADINI: Okay. That I've heard.

DR. YARSKY: Right.

MEMBER CORRADINI: But that is not -- go ahead. I --

DR. YARSKY: Now, what we're doing with FAST is we're making it so that FAST and TRACE can mesh together.

MEMBER CORRADINI: Oh, okay.

DR. YARSKY: Can mesh together seamlessly, right? Now, that's how TRACE works today, but that is not what we did in this project. So I want to make sure that we're clear in terms of what capabilities we now have versus what was done for Brunswick. So we have this new capability and it would be really great to use. However, in order to develop the core model in TRACE, we had developed a number of mapping utilities to do things like take the exposure distribution from the PARCS calculation or to take, like, burnup history information from FRAPCON calculations to sort of import that into TRACE.

And so while we've developed this new thermal-mechanical capability and we have more advanced models and features, that kind of meant we couldn't use any of the utilities that we had developed for doing all this mapping. And so in order to support the current licensing schedule because we weren't able to exploit these new thermal-mechanical models, we sort of had to go backwards, so we were still able to use our mapping utilities but we couldn't exploit --

CHAIRMAN MARCH-LEUBA: Bottom line, this

particular calculation was not a research project but it was an engineering calculation.

DR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: And you had to use what --

DR. YARSKY: You got to do what you got to do to get it done on the schedule. So even though we have these advanced capabilities, we couldn't use them to push this analysis over the finish line, so it resulted in us having to use a more simplified thermal-mechanical capability --

CHAIRMAN MARCH-LEUBA: But you hope to be ready for the next --

DR. YARSKY: Right. Exactly. So we hope to have that ready to go for the next MELLA+.

MEMBER REMPE: Well, do you expect there will be any difference? I mean, basically, you've got the same capability, right?

DR. YARSKY: I expect it will be different because we're using this really simplified approach here. So what we've done to account for that is that we are doing a variety of calculations of different gap conductances.

MEMBER REMPE: Right. I do remember that part. Okay, okay.

DR. YARSKY: And once we have the detailed thermal-mechanical modeling, this need to do these large number of gap sensitivity studies, we don't perceive a need to do that same kind of sensitivity study in the future once we're able to exploit our advanced TM modeling capabilities.

MEMBER CORRADINI: So maybe this is for closed session, but I think I can ask the question. So the way I understood you did is you did HGAP sensitivities.

DR. YARSKY: Right.

MEMBER CORRADINI: Okay. But that doesn't change the flow area.

DR. YARSKY: It does not change the flow area.

MEMBER CORRADINI: So what did you do there? Because as I have these transients, there could be distortion of the fuel rod geometry and I don't remember what is typically done to anticipate or bound that.

DR. YARSKY: So in short, we didn't consider any flow area change, but what immediately comes to mind is if cladding bursts, so if you have a burst --

MEMBER CORRADINI: I'm not even that

dramatic. The claim doesn't burst, but it starts changing in the timescale of the transient, which would change the flow which would change the heat transfer, blah, blah, blah. That's not done?

DR. YARSKY: Oh, that is not done.

MEMBER CORRADINI: Does the applicant do anything to do a sensitivity on that?

DR. YARSKY: We would have to save that for closed session.

MEMBER CORRADINI: Okay, fine. That's fine. Thank you.

DR. YARSKY: Well, I'm going to move on. The short takeaway from this slide is that, because of this shortcoming in our thermal-mechanical approach just for this project, we did a large number of HGAPs and sensitivity studies.

So to start the TRACE/PARCS calculation, once we have all of those elements from PARCS/PATHS, we have to perform an initialization. This is very similar to what we had done in the past but eliminates one step. First, we run TRACE in a standalone mode to establish core boundary conditions, then we run a coupled steady-state TRACE/PARCS calculation, but what we do here is we use numerical solution technique in the coupled steady-state that matches the solution technique that we will exploit in the transient calculation.

What we've implemented in TRACE are higher order methods that allow us to forego what we had previously done, which is Courant number weighted, graded nodalization. But these higher-order spatial methods allow us to sort of get by without having to do unusual graded nodalization in the TRACE calculation.

MEMBER CORRADINI: I'm not sure what that means.

DR. YARSKY: So previously what we would do if, when we were just using the semi-implicit solver in TRACE, is we would optimize the nodalization for the hot channel axially to have a uniform Courant number. So you would have nodes that were very small at the beginning of the channel and nodes would get bigger as you moved to the outlet of the channel, but you would have this weird non-uniform axial nodalization for the channel.

In certain instances, that forces you to make engineering approximations where we would potentially have to move spacers to align with node boundaries. So it became a bit of an art --

MEMBER CORRADINI: So that's where you put the K loss?

DR. YARSKY: Right. So it became a bit of an art to determine this non-uniform axial nodalization. And even establishing it for the hot channel, you didn't have uniform Courant for the other channels. So there was some distortion there. And the velocity changes throughout the event, you know, so even optimizing the channel nodalization for Courant limit at one point doesn't necessarily mean it's optimized for all points.

This motivated the staff to develop higher-order spatial methods so we could reduce, essentially, the diffusion associated with the spatial error. And then what you can do is you can kind of crank down the time step size and then you can eliminate the fusion. So we can perform a time domain stability-like calculation without having this constraint on having to develop these non-uniform axial nodalizations.

CHAIRMAN MARCH-LEUBA: So have you performed nodalization studies to make sure you converge?

DR. YARSKY: Well, these kinds of studies were done separate from this project.

CHAIRMAN MARCH-LEUBA: Sure.

DR. YARSKY: But these have been studied particularly with respect to what sort of a maximum time step size we can get away with, and so those studies are done to look at the diffusion aspects with respect to, you know, can we run this at one-tenth Courant limit time step size, can we run it at one-half Courant limit time step size? So the purpose of this is to determine what that --

CHAIRMAN MARCH-LEUBA: Because when I was doing this work, I almost convinced myself that it was not Courant that was doing it but it was defining the void fraction precisely --

DR. YARSKY: Oh, yes.

CHAIRMAN MARCH-LEUBA: -- along the --

DR. YARSKY: Yes, we agree with that. So the nodalization we have still has a refined node size around the boiling boundary because research confers with that conclusion that it's really the location of the boiling boundary, which is really what is -- you would see these big differences when you did the refined nodalization to Courant optimize the channel, and we agree that that's really narrowing down on the precise location of the boiling boundary which was creating those big differences.

CHAIRMAN MARCH-LEUBA: So somebody has to run those calculations and have seen the results would be tempted to use 12-inch nodes with a higher-level model and everything is going to fit perfectly --

DR. YARSKY: No. So we still do fine nodalization at the channel inlet around the boiling boundary, but then it's six-inch nodes otherwise. But this also means that we don't have to do things like re-nodalize the steam line.

CHAIRMAN MARCH-LEUBA: A standard nodalization, that's good.

DR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: Keep going. We have to go to the axial calculations.

DR. YARSKY: Eventually we have to get there. As I said before, we take the coupled calculation and compare it to PARCS/PATHS to ensure the adequacy of the channel group and then we do a five-second null transient. The transient calculation restarts from a coupled steady-state. We have the five-second null transients. We did a five-second period that's like a null transient but just with noise turned on to make sure the noise is behaving appropriately. And in the transient calculation, we model explicitly the various trip systems responses. Where we can, we use control systems to model the behavior of the operators. And just for the purposes of our staff confirmatory analysis, we diagnose a condition of fuel damage if the PCT exceeds 2,200F.

And so that's what I had for our methodology. As I understand, on the agenda we're going to skip the discussion of Tmin.

CHAIRMAN MARCH-LEUBA: We continue in open session and --

DR. YARSKY: And we're going to talk about next is the reference case analysis.

CHAIRMAN MARCH-LEUBA: On the agenda, we have unit differences. Is that what you're going to talk about?

DR. YARSKY: Oh, yes, yes, yes. I almost forgot about unit differences.

CHAIRMAN MARCH-LEUBA: These are the ones I have, and are you still following the computer?

DR. YARSKY: Hold on. Let me see.

CHAIRMAN MARCH-LEUBA: We must have passed on the draft . . .

DR. YARSKY: I have the, I have the unit differences slide.

MEMBER CORRADINI: I didn't see slides for that.

DR. YARSKY: Can we maybe break now and

then I can just move from this machine to this machine.

CHAIRMAN MARCH-LEUBA: Let's have a ten-minute break. We'll reconvene at 9:30.

DR. YARSKY: That sounds good, yes.

CHAIRMAN MARCH-LEUBA: Okay. We're off the record.

(Whereupon, the foregoing matter went off the record at 9:17 a.m. and went back on the record at 9:27 a.m.)

CHAIRMAN MARCH-LEUBA: We're back in session. This is still open session, so, Peter, continue.

DR. YARSKY: Yes. So I wanted to give a quick presentation about the differences in the units at Brunswick. There are key differences that relate to the confirmatory analysis. The first is the bypass capacity. The turbine bypass capacity for Unit 1 is much smaller than the bypass capacity for Unit 2. It's 15.5 percent for Unit 1 and 55.5 percent for Unit 2.

They also have different inlet orifices for the fuel channels, so the Unit 1 orifices are -- hold on. I think this may be, this slide may -- the Unit 1 orifices are tighter orifices than the orifices in Unit 2. So I think these values may be reversed.

And then, lastly, there's a difference in the core flow rate with the Unit 2 core flow rate being lower.

CHAIRMAN MARCH-LEUBA: I mean, the tighter orifice unit has higher flow?

DR. YARSKY: The tight orifice is Unit 2 and that --

CHAIRMAN MARCH-LEUBA: So those are likely reversed, the numbers you're showing there?

DR. YARSKY: Let's see. The tight orifice --

CHAIRMAN MARCH-LEUBA: Okay. You're showing Unit 1 243 --

DR. YARSKY: Yes, okay. So Unit 2 has the tight orifices and the lower core flow rate. Right. Yes, this is correct, this is correct.

MR. BORROMEO: This is what was provided to us in the supplement during our acceptance review, so that's correct.

DR. YARSKY: Okay, yes. So Unit 2 has the tight orifices and the lower core flow rate.

MEMBER REMPE: There's an RAI, I think, called unit differences for your audit calculations, and so that's where we ought to get the correct numbers.

DR. YARSKY: Okay. In terms of the bypass capacity, the research staff confirmatory analysis is based on --

CHAIRMAN MARCH-LEUBA: Sorry. Were we talking about both of them have the same fuel?

DR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: They're all full-loaded --

MR. BORROMEO: ATRIUM 10, yes.

DR. YARSKY: So, first, in terms of the bypass capacity, the research staff performed its analysis based on the Unit 1 bypass capacity.

CHAIRMAN MARCH-LEUBA: Sorry. Whenever you speak, tell who you are.

MR. BORROMEO: That was Josh Borromeo.

DR. YARSKY: We have previously recommended analyzing ATWS conditions at the plant-specific bypass capacity because it's difficult to tell beforehand if a higher or lower system pressure would be more limiting from the standpoint of ATWS-I. Calculations submitted by the licensee have indicated that the Unit 1 bypass capacity is more limiting, and so that was the basis for selecting that value for the reference calculation for the research analysis. So we're using the Unit 1 bypass capacity.

The Unit 1 orifices are looser than Unit 2 orifices, and tighter orifices are stabilizing so we've analyzed with the Unit 1 orifices. And this is consistent with the selected bypass capacity in that both are Unit 1 values. However, the core flow rate we analyzed at the Unit 2 value. So the core flow rate is lower in Unit 2 than Unit 1, so we performed our calculation at the lower core flow rate because this should be bounding, so it's a Unit 2 core flow rate.

CHAIRMAN MARCH-LEUBA: Right. Well, that's the 100-percent flow rate, right?

DR. YARSKY: The 100-percent flow rate is 3.5 percent different, so we just applied a 3.5 percent difference to the --

CHAIRMAN MARCH-LEUBA: You apply that to the speed of the pump or the efficiency of the pump to --

DR. YARSKY: That's just the flow.

CHAIRMAN MARCH-LEUBA: Correct. But you did not change the pressure drop coefficient?

DR. YARSKY: No, no. So this is done by putting in a different target core flow rate to the pump flow controller.

CHAIRMAN MARCH-LEUBA: Yes. But does it affect, the question is does it affect the natural circulation flow? It probably shouldn't. The fact that you have a larger pump or a smaller pump --

DR. YARSKY: Yes, it should have no impact with respect to the natural circulation flow that develops, except that since you're starting from a lower core flow rate you're on a higher rad line. So you can think that the natural circulation curve would be the same, but where it intersects will be on a higher rad line and it will be a slightly higher rad line because the flow rate is very similar to just a little bit lower --

CHAIRMAN MARCH-LEUBA: Yes, because I'm thinking of lowering the flow width here a half percent, you put in a smaller pump.

DR. YARSKY: Right. You can think of it that way.

CHAIRMAN MARCH-LEUBA: And if you have a smaller pump, you need to pull control rods to get the same power. Okay.

DR. YARSKY: Yes. It was a higher rad line. Okay. So it's very much like Unit 1, except it's at a slightly lower core flow rate to be consistent with the Unit 2 value, and we think that is the combination of parameters that will produce the most conservative result.

CHAIRMAN MARCH-LEUBA: I'm going there because I'm a little concerned that the flow is coming out here low, which you're going to tell us in a moment. I'm trying to figure out why. Keep going. I will keep asking about that.

DR. YARSKY: Okay. So that's everything for the unit differences. So now we can talk about the reference scenario analysis.

So, first, we'll get to the sequence events and then after we have an idea the overall sequence of events that occur that we can go through on each particular key parameter, we can go through the plots, and then we'll talk about the key results.

So at ten seconds in problem time is when the event is initiated, and this event starts with a turbine trip. And this is modeled by fast closure of actually the turbine control valve, but in the plant it would be the turbine stop valve. This initiates the dual recirculation pump trip and the isolation of extraction steam to the feedwater heater cascade.

About one second later is when peak dome pressure is reached at about 8.5 megapascals, and the first safety relief valve bank opens. This is also around the time when the turbine bypass valve opens.

Around 40 seconds, we predict that the core will become unstable with the out-of-phase mode being more limiting but quickly bimodal non-linear oscillations develop.

CHAIRMAN MARCH-LEUBA: I read some of your staff -- what feedwater temperature cooling rate you're assuming? Are you assuming --

DR. YARSKY: This assumes a 1.3 Fahrenheit per second feedwater temperature decrease.

CHAIRMAN MARCH-LEUBA: The one that's very conservative, correct?

DR. YARSKY: We would say that it's the more conservative of the rates that we analyzed.

CHAIRMAN MARCH-LEUBA: Okay.

MEMBER REMPE: But they ultimately went to something that they justified that was not --

DR. YARSKY: Yes.

CHAIRMAN MARCH-LEUBA: So this is not the best estimate, 40 seconds.

DR. YARSKY: Right, right. So 1.3 Fahrenheit per second is a faster rate. That was sort of the initial rate that was sort of submitted as part of the application, but then that rate tends to change to 0.5 Fahrenheit per second. And that's sort of like the baseline rate. These calculations were performed with the 1.3 --

CHAIRMAN MARCH-LEUBA: This is with the 40 seconds by a factor of two or three because by 40 seconds the pump has already tripped.

DR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: So now you're counting on the feedwater temperature.

DR. YARSKY: Yes. Around 60 seconds, we see the level increase and it reaches a steady about one meter in the TRACE calculation. About 70 seconds is where we see the first significant fuel heatup with PCT being reached between about 100 or 150 seconds.

CHAIRMAN MARCH-LEUBA: And the hottest roll in the core, right?

DR. YARSKY: Right. So that's the --

CHAIRMAN MARCH-LEUBA: It's a single pin.

DR. YARSKY: When we're referring to PCT here, this is the, like, hottest point on any of the rods in the core, but if you look at, say, a plot of PCT, it doesn't represent the history of the PCT at the PCT point, just to be clear when we talk about PCT. We can also talk about the history, like the temperature histories with respect to certain rods or different positions on rods. But here the PCT reflects the total sampling of all cladding temperatures throughout the core.

At 125 seconds, this is problem time, operators initiate standby liquid control system injection. And at 130 seconds, operators terminate feed flow and begin the control level to top of active fuel plus 90 inches.

Around 140 seconds, the core inlet subcooling begins to decrease rapidly. And around 240 seconds is when we show operators restoring feed flow to maintain the level at top of active fuel plus 90.

So, first, I'm showing two plots here. This is the dome pressure on the left and the total SRV flow on the right. And this just indicates that in response to the turbine trip the pressure increases, and the pressure pulse reaches about 8.5 megapascals. The pressure then decreases and is being controlled by the cycling of the SRVs in combination with the turbine bypass. And you can see that after about 200 seconds the lowest SRV bank closes and then remains closed.

In terms of core power, the initial power peak is due to void collapse from the turbine stop valve closure causing back pressure wave. That power then decreases in response to void feedback and the dual recirculation pump trip. This brings the reactor to a natural circulation condition around the 25-second mark and then power will start to slowly increase in response to decreasing feedwater temperature, which causes an increase in core inlet subcooling. This causes the core average power to increase. Around 40 seconds is where we see power oscillations that appear a bit irregular, but this is a combination of a density wave driven instability kind of layered on top of power oscillations due to SRV cycling.

CHAIRMAN MARCH-LEUBA: Is this the core average power is the power of --

DR. YARSKY: This is the core average power.

CHAIRMAN MARCH-LEUBA: So oscillations on a channel level are much larger?

DR. YARSKY: Right. So if you were to look at the hot channel power oscillation, the oscillation magnitude would show that there's an out-of-phase mode.

CHAIRMAN MARCH-LEUBA: This plot is misleading to a neophyte.

DR. YARSKY: But it does present, like, a global picture in terms of the timing of when key features of the event occur. We predict that the reactor becomes stable around, like, 150 seconds, even though there's continued SRV cycling. And, eventually, very late in the transient, we predict a bit of a power increase due to increased core subcooling after feedwater flow restoration.

CHAIRMAN MARCH-LEUBA: So, Joy, I won't call you a neophyte, but you understand these oscillations are on both sides very large and this is the sum of two channels.

MEMBER REMPE: Right.

CHAIRMAN MARCH-LEUBA: That's why they're so, they don't look like instability, they look like what? Okay. If somebody is reading the record, they know we understand it.

DR. YARSKY: Okay. We move on to core flow rate. There's the reduction in core flow rate due to the coast down from the dual recirculation pump trip. Core flow is about 20 percent during the natural circulation phase, and then later we show the core flow rate being reduced by the effective manual operator actions to reduce the level following intervention at 130 seconds. And then late in the transient, once the operators begin the restoration of the feedwater flow, there's an increase in the core flow rate.

If we look at the feed temperature and inlet subcooling, here's where we're showing the feedwater temperature on the left and we assume a decreasing rate of 1.3 Fahrenheit per second following the trip of the turbine. And this rate is the original transient analysis rate.

On the right, we're showing the subcooling response, and what you can see is there's this oscillation of the subcooling. This is due to SRV cycling. So as the RPV pressure increases or decreases, Tsat increases or decreases, so that's what's causing these jitters in the subcooling. But, in general, the subcooling increases in response to the decreasing feedwater temperature early on, and then there's a reduction or a rapid reduction in the subcooling once the feedwater flow is terminated.

MEMBER CORRADINI: The operator action is at 90-something seconds.

DR. YARSKY: In problem time, it's 130 seconds.

MEMBER CORRADINI: Oh, 130 seconds.

CHAIRMAN MARCH-LEUBA: The turbine doesn't attain on TRACE time. So it's 120 seconds after that.

DR. YARSKY: Right.

MEMBER CORRADINI: But I'm sorry that I'm confused.

CHAIRMAN MARCH-LEUBA: Can you go back to the time line sequence?

DR. YARSKY: Yes.

MEMBER CORRADINI: Sorry.

CHAIRMAN MARCH-LEUBA: One more.

DR. YARSKY: One more. Okay. So the event initiates at 10 seconds in problem time.

MEMBER CORRADINI: Okay, all right. So now go back to the plot that I was going to -- so I guess I assumed that the subcooling decrease at about 100 seconds was due to operator action. That's incorrect?

DR. YARSKY: That is incorrect. So the --

MEMBER CORRADINI: Subcooling decrease --

DR. YARSKY: Subcooling decrease is later. And there's actually even a delay. So, like, once the operators stop feed injection, you still need, the cold water that's already been injected has to move through. So there's a delay on top of that. So you see that this dramatic decrease in the subcooling doesn't occur until later, like 140 - 150 seconds.

MEMBER CORRADINI: So what's causing the subcooling decrease from 90 to 150?

CHAIRMAN MARCH-LEUBA: The cooling is a mixture of the feedwater temperature which you have on the left and the amount of Tsat liquids. So if you increase the steam flow, for example, you have less water circulation and then you get a little temperature. It's a combination of two things. If you have a --

DR. YARSKY: So this increase here --

CHAIRMAN MARCH-LEUBA: -- flow change.

DR. YARSKY: Yes, the decrease that's occurring at 90 seconds isn't a result of any operator action --

MEMBER CORRADINI: It's a change in the recirculation ratio?

DR. YARSKY: Right. So during the instability, the core average power is changing, so you have a change in the average steam flow rate and exit quality. And then that is affecting how much flow you have coming out of the separators at that Tsat.

MEMBER CORRADINI: Yes, I'm with you there. I'm with you. What I'm trying to get at is, since all these wiggles confuse the heck out of me, a plot that would illuminate might be the recirculation ratio as a function of time because --

CHAIRMAN MARCH-LEUBA: It's a previous slide, right?

DR. YARSKY: Core flow rate.

CHAIRMAN MARCH-LEUBA: Which is about proportional. So this would be the recirculation flow, the recirculation plus feedwater flow.

MEMBER CORRADINI: Right. And there's no operator action in this timing until 130 seconds?

DR. YARSKY: Right. Well, the operators will begin standby liquid control system injection at 125 seconds of problem time.

MEMBER CORRADINI: Problem time.

DR. YARSKY: Yes.

MEMBER CORRADINI: Okay. It just, it just, so to a first approximation, the recirculation ratio is this plot?

DR. YARSKY: I'm really hesitant to say that because there's also the effect of, because the feedwater flow controller is still active and working even though the operators are not manually controlling. So there's still changes in the feedwater flow rate.

MEMBER CORRADINI: You've answered my question --

DR. YARSKY: It's very difficult for me to say exactly how close this would be to just the recirculation ratio.

MEMBER CORRADINI: But to Jose's point, for just for me to understand, what struck me was the increase in subcooling and then the slight decrease in subcooling and then the falloff. If the falloff is operator action, the initial slight decrease has to be of how much feed flow there is versus --

CHAIRMAN MARCH-LEUBA: I believe it's the feedwater controller level.

DR. YARSKY: There are a number of effects that are all going on. So in terms of this decrease here, first, the jagged miss is SRV cycling, so just imagine you're drawing like an average through that and you see a bit of an arc here. There's an overall system response that there's a combination of increasing steam production rate in the core as a function of the instability increasing the average power level, but also the feedwater controller is still active and changing the rate of feedwater flow injection to try and account for a change in level.

So there's a point where you trip the recirculation pumps the level increases because the --

MEMBER CORRADINI: The feedwater controller does something to draw back on that to keep

--

DR. YARSKY: So it's going to draw back, but also, due to a nuance of the modeling in TRACE, and we'll talk about this a little bit later, but it's probably a mistake. The feedwater control operates on a three-element controller, so it responds also to the flow going down the steam line. In the TRACE calculations, that sensing location is downstream of the SRVs, which builds into our feedwater flow controller a bias in the level that it's trying to reach. So there are these two aspects of the feedwater flow that's responding to the change in the core steam production rate.

Overall, I think you would have to sort of go through all those smaller issues to really build up an understanding of this trajectory here. But the key takeaway is still, when the operators cut the feedwater flow, you do see a small delay and then a significant reduction in the --

MEMBER CORRADINI: All right. Thank you. That helps, that helps. Thank you. Oh, since I have you, the straight linear line is an assumption to bound what really the plant's response would be.

DR. YARSKY: This is the bounding based on a submittal by the licensee. I think the analysis that NRR is going to talk about tomorrow is performed at an even slower feedwater temperature decrease rate, and we'll present studies that research has done using a slower feedwater temperature decrease rate. So this would be the most conservative rate that we've analyzed.

MEMBER CORRADINI: That's what, I guess, I was getting at. Okay.

DR. YARSKY: Yes. As we were just talking about with the feedwater flow response, I'm showing here a figure here on the left that's showing the level. Early on, after the recirculation pump trip, the level starts to increase, but this increase makes sense because of the reduction in the core flow rate because of the recirc pump trip. But a bias builds in, which we believe to be a function of a three-element controller not compensating for steam flow due to the sensing location of steam flow in the controller.

CHAIRMAN MARCH-LEUBA: If you look at the figure on the left, remember the one we were talking about before? The increasing level implies I'm pumping more cold water. When the level stops, I'm pumping less cold water. And right around 60 or 70 is when the feedwater flow is starting going down. At 90 seconds, you see --

MEMBER CORRADINI: Good point. Thank you.

DR. YARSKY: Right. And so when the level evens out, that means that the feed is exactly compensating the steam flow. Then you can see the effect of the operator intervention on the level. The level starts to decrease, and it's around 240 seconds when the level hits top of active fuel plus 90 inches. At that point, the operators will restore the feedwater flow to maintain the level. So the figure on the right is showing when the operators intervene to stop feed flow and when they re-establish feed flow.

So here we can talk about the peak cladding temperature. So the figure here provides in blue the peak cladding temperature from the entire core.

CHAIRMAN MARCH-LEUBA: Can you say what Tmin you're using for this or is --

DR. YARSKY: Yes, the Tmin value that we're assuming in this calculation is the homogeneous nucleation temperature plus contact temperature.

So what we've also plotted here in black and in red are the, I don't want to say PCT, the highest temperature on averaged power rods in two candidate hot assemblies.

CHAIRMAN MARCH-LEUBA: No pin peaking factor?

DR. YARSKY: No pin peaking factor.

CHAIRMAN MARCH-LEUBA: So this is 100-percent average?

DR. YARSKY: Yes. So it's a bit of an input error.

CHAIRMAN MARCH-LEUBA: So this is like the median, you can think of it being like the median response.

DR. YARSKY: It's like the average rod response in candidate hot assemblies is being plotted along side the PCT. The PCT is actually the PCT, but these other two plots can give you an idea of what's happening in these candidate hot assemblies but on average, not at what's happening in their hottest rods.

CHAIRMAN MARCH-LEUBA: I like to think of it in simple ways: half the rods are going to be lower than the red line.

DR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: It's like the median.

DR. YARSKY: Yes, exactly.

CHAIRMAN MARCH-LEUBA: And the other half will be higher, and the hottest one is blue.

DR. YARSKY: Yes. What we show in the TRACE calculation is this prediction of an early limited heatup. This is because, in TRACE, we predict dryout during the dual recirculation pump trip that then causes a fuel heatup. So this is a result from TRACE that we attribute to conservatism in the prediction of critical power in TRACE. This leads to the PCT going up to about, so, like, 900 or 1,000 Fahrenheit during the natural circulation phase in the TRACE calculation and this is limited to, like, a smaller population of rods. As you can see in the hot assembly, this dryout is not predicted for the average rod.

MEMBER CORRADINI: So the blue line is seeing early dryout?

DR. YARSKY: Yes. So in the --

MEMBER CORRADINI: And what are you using for the predictor there?

DR. YARSKY: So the CHF is being predicted by Biasi.

MEMBER CORRADINI: Versus the lookup table?

DR. YARSKY: Versus the lookup table.

MEMBER CORRADINI: And you picked Biasi because it gives you an earlier dryout, because -- I mean, I think this is in open session. Everything that I've seen in terms of cross comparisons of public CHF correlations is the lookup table tends to be more realistic. So is Biasi --

DR. YARSKY: Biasi is more conservative.

MEMBER CORRADINI: That's what I thought. That's what I thought.

MR. STAUDENMEIER: This is Joe Staudenmeier, Office of Research. Actually, Biasi CHF correlation has been transformed into a critical quality correlation, and so that's calculated MCPR and it also is used in the lookup table, so it will take the minimum value of either one of them.

MEMBER CORRADINI: Oh, so it's actually doing some combination?

MR. STAUDENMEIER: It's doing some combination of both.

MEMBER CORRADINI: Is this the most recent lookup table? Because in the original TRACE, it had the earlier version of it.

MR. STAUDENMEIER: The version of lookup table now I think is the 19 --

MEMBER CORRADINI: Not the 2006 one?

MR. STAUDENMEIER: It's not 2006.

MEMBER CORRADINI: Okay.

MR. STAUDENMEIER: We haven't moved to 2006 --

MEMBER CORRADINI: That's fine, that's fine. I just wanted to understand what's causing the bump. So you guys are looking at the minimum between them?

MR. STAUDENMEIER: Right. So the Biasi critical quality correlation will be, that will come into effect more at the high void fraction up at the other high end looking at running out of film and drying out up there. The CHF correlation will be more limiting down in the high-power region of the core where you have a lot more water. And that's what really determines it when you start going in to flow reversals and reducing flow down in the lower part of the --

MEMBER CORRADINI: Thank you. Thank you very much.

DR. YARSKY: Yes, I think, in short, we're using a conservative correlation with this beginning part and that's why TRACE is showing this early dryout.

However, when we get into the unstable

phase, that's where we see the significant fuel heatup, and that part would occur regardless of this earlier dryout that we're predicting in the TRACE calculation.

MEMBER CORRADINI: Right. The only reason I asked about the blue line was, to a first crude approximation, the difference between red, black, and blue, that delta temperature is essentially representative of the stored energy that eventually has to get released, or you don't think that's correct?

DR. YARSKY: It's not really that. So remember this isn't the history of --

MEMBER CORRADINI: Oh, this is not --

DR. YARSKY: This is not the history of a given location.

MEMBER CORRADINI: It's everywhere.

DR. YARSKY: Right. So what's happening is you can think the location of a hot spot moves from this early dryout point that's high in the bundle, and then when you get to the unstable phase that dryout point was closer to the peak power location so it's lower in the bundle. So there's a switch from the locations. That stored energy doesn't really affect it.

MEMBER CORRADINI: Okay, fine.

DR. YARSKY: The difference between, say, the black curve and the blue curve is because of the black curve is representing the average rod in the hot bundle and not the peak rod in the hot bundle. They would be in much closer agreement there, so it's really a radial peaking factor difference that's explaining the difference between the black curve and the blue curve.

MEMBER CORRADINI: All right. Thank you.

DR. YARSKY: However, this initial dryout phase we think is just a conservatism in the TRACE prediction of the critical power during that part of the transient. However, later, that PCT location moves and we see this dramatic increase in the PCT during the unstable phase reaching a maximum of about 2,100F at around 100 seconds.

What we show then at the very last part of the transient, there's this increase in PCT again. This is a result of in the TRACE prediction we showed subcooling increasing after the operators start the feedwater pumps again, and this leads to, like, a second peak PCT, but the second peak PCT is always significantly lower than this first peak PCT.

CHAIRMAN MARCH-LEUBA: You're talking

about the blue, blue curve --

DR. YARSKY: How the blue curve is going up at the end.

CHAIRMAN MARCH-LEUBA: Because the red one around to 70 --

DR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: Okay. Keep going.

DR. YARSKY: So the second peak PCT occurs late in the transient and responds to an increase in the inlet subcooling, and TRACE is likely over-predicting the degree of increased subcooling once feedwater flow is restored because of an under-predicting compensation heat transfer in the steam space above the downcomer liquid water level.

When performing these calculations, we generally perform them with the feature in TRACE called level tracking active in the vessel nodes and the downcomer to be able to keep track of where the liquid steam interfaces during the evolution of the event. However, once that liquid water level drops below the feedwater sparger and then TRACE starts injecting feedwater flow into that steam space, the level tracking feature is going to constrain the interfacial heat transfer area to be determined by the geometry of the downcomer. We believe this creates an underestimation of the interfacial heat transfer area, but this is a conservatism in that the liquid will retain more of its subcooling as it moves into the liquid space of the downcomer.

But as a result, in the TRACE calculation, we see a second peak in the PCT late in the transient. However, the second peak is always bounded by the first peak. And it makes sense because, even if you were to do the same event all over again, by the time of the second peak, to have that exact same subcooling and level, SLCS had been injecting by this point for about two minutes, so you have one in the core that's limiting any kind of power response late in the transient.

So from our reference scenario analysis, what we've been able to confirm is that the manual operator actions to inject for and reduce water level are effective to suppress the instability and to bring the reactor to a downward PCT trajectory eventually. The calculations performed with the worst combination of feedwater temperature rate, operator action timing, and gap conductance produce PCTs below 2,200F, which we've taken as our criterion for fuel damage. This indicates no fuel damage.

TRACE may under-predict the compensation hate transfer once feed flow is restored and the feedwater injection is in the steam space above the downcomer liquid level. But the current calculations are conservative.

So I think that's everything I have for sort of this reference scenario, unless we can move into --

CHAIRMAN MARCH-LEUBA: So what's left of the sensitivities?

DR. YARSKY: Next we can move into the sensitivities.

CHAIRMAN MARCH-LEUBA: We have a break scheduled for now, but we had one a half an hour ago, so let's keep going.

DR. YARSKY: Okay.

MEMBER CORRADINI: So the sensitivities are closed or open?

CHAIRMAN MARCH-LEUBA: Open. The only thing that we have closed left is the calculation versus the vendor code, the comparison to the vendor code.

DR. YARSKY: Okay. In terms of sensitivity studies, first I'd like to talk about gap conductance, and this is a key part of the methodology that we applied to Brunswick. Next, we'll talk about the feedwater temperature transient and, lastly, effect of operator action timing.

So this table summarizes the result of our gap conductance sensitivity study. As we discussed earlier, we analyzed a series of gap conductances ranging from 3 kilowatts per square meter-Kelvin to 30 kilowatts per square meter-Kelvin in increments of 3 kilowatt per square meter-Kelvin for all of the cases.

MEMBER CORRADINI: And this is done by a side calculation in FRAPCON?

DR. YARSKY: No. So these HGAP values, we're inputting them into TRACE directly.

MEMBER CORRADINI: No, that I understand. But I'm asking these are computed based on a correlation which is a -- what I'm trying to understand is why 3 to 30?

DR. YARSKY: Okay. So these values are derived from a NUREG that the NRC wrote in 2001 time frame. So for our generic 10 by 10 fuel assembly, we performed a variety of calculations with FRAPCON.

MEMBER CORRADINI: Okay. Then that's what I was --

DR. YARSKY: And so these are FRAPCON results for a generic 10 by 10 fuel assembly. So it's --

MEMBER CORRADINI: And it's a function of burnup?

DR. YARSKY: Yes. And so it's a function of burnup and LHGR, so it's a combination of LHGR and burnup. And then what we've done is we've taken those generic results for that generic 10 by 10 assembly and then pulled results that are appropriate based on the range of linear heat generation rate and exposure.

MEMBER CORRADINI: Okay.

CHAIRMAN MARCH-LEUBA: But for this calculation, you make it uniform. If it's --

DR. YARSKY: Right. So in this calculation, it's one value for the entire core.

MEMBER CORRADINI: Okay. That part I get.

DR. YARSKY: But the 3 and the 30 come from a set of generic FRAPCON calculations for a representative 10 by 10 BWR fuel assembly, and it covers a range of LHGR and exposures that are representative of the limiting cycle exposure point that we're analyzing.

CHAIRMAN MARCH-LEUBA: Basically, 30 is essentially the gap completely closed being on clad on contact --

DR. YARSKY: Right. But we also wanted to make sure that we captured fresh.

CHAIRMAN MARCH-LEUBA: Which is the 3.

DR. YARSKY: The 3, yes.

MEMBER CORRADINI: Okay. So that's the range. So then is there a consideration of the thermal conductivity of the fuel that also is a function of the burnup?

DR. YARSKY: So there is, in this current calculation, we do not consider TCD, or thermal conductivity degradation. However, based on the limiting point that we're considering, which is beginning of equilibrium cycle, this is a low exposure. On average, the fuel assemblies have a low exposure, so this shouldn't have a significant impact.

MEMBER CORRADINI: Because that's where you think the limiting --

DR. YARSKY: That's where the old model, low exposure is where the model without thermal conductivity degradation best agrees with the model that has it. But that aside, so we understand that's a limitation of the model because we're using this simplified for a mechanical approach. The hopes are that if there's a difference in the conductivity, as a result of exposure, it will be a small difference because we're looking at a lower exposure but we're covering that same kind of effect by looking at this range of HGAPs.

MEMBER CORRADINI: So if we were to say it to you back, I think I know what you just said. You're saying if I, I'll use the word conservative HGAP that covers the fact of the TCD effect?

DR. YARSKY: Right, right. So since we're at low exposure, we said maybe we could do something similar for fuel thermal conductivity, but the effect of HGAP will be more important. And we're doing a wide range of HGAP, so it should cover something like the conductivity effect.

MEMBER CORRADINI: So I know you guys always never have enough to do, but if you were to go back to that early 2000 study and re-do it with now the new technique that you've got with TRACE and FAST, you could actually --

DR. YARSKY: Well, we're not planning on re-doing that study from 2001. We're just going to analyze whatever core we have to analyze. And, in fact, we've already performed --

MEMBER CORRADINI: In the new method.

DR. YARSKY: Yes. We've already performed FAST calculations for every rod type, for every rod group, for every assembly.

MEMBER CORRADINI: Okay, fine.

DR. YARSKY: In Brunswick, it's just because of the time frame to produce this analysis, we weren't able to take those explicit thermal-mechanical properties calculated for FAST in those detailed models and map them over to the TRACE calculation. So this approach we're only going to ever do once.

MEMBER CORRADINI: I understand. But where I was kind of searching for is the way you describe it, the orange line, in some sense, is an engineering judgment of a lot of sins covered up by HGAP --

DR. YARSKY: Yes, we're covering a lot of warts with just doing this wide range of HGAP sensitivities over a fine step, and then we're just going to pick the worst one and say, we'll just pick the worst one and say that's the PCT?

MEMBER CORRADINI: Okay, thank you.

DR. YARSKY: All right.

CHAIRMAN MARCH-LEUBA: And do you have any insight of what the HGAP impact is? What is the effect that changes PCT? Because once you go into film boiling, the low H number --

DR. YARSKY: Yes, so you could spend days sort of unpacking everything that is related to HGAP. So it has two primary effects, and they kind of compete with each other and it's really hard to say up-front which one is going to be more important.

So the first is it affects void coupling by affecting the dynamic response of the nuclear power reaching the coolant, and so, if you have, say, a high value of HGAP, this can allow the nuclear power to more rapidly reach the coolant and this can have a potentially destabilizing effect. It could be potentially destabilizing, but the fuel pins in 10 by 10 assemblies are, like, kind of small, so they can go either way. It can be a stabilizing or destabilizing effect from that.

But in terms of how you get to PCT, that's only half the story because now you also have the approach to failure to rewet, which is dictated by the fuel temperature ratcheting phenomenon. So how effectively can nuclear heat be removed from the fuel during the rewet phase of a dryout rewet cycle? And so the HGAP then can have an impact on the evolution of dryout rewet cycling. It can move that rate of overall temperature ratcheting. And then, lastly, it has an impact on stored energy.

So it has these different effects that come in at, they can shift certain key stages in the evolution of the PCT transient. So it can affect the initial instability inset, it can affect then the peak power that's achieved during the non-linear phase, it can affect the temperature rate of increase during ratcheting. And so that all then compounds to affect the PCT.

CHAIRMAN MARCH-LEUBA: In short, what this shows is that HGAP not only has an impact on the linear instability, which we've known for 30 years, but it has an impact PCT during dryout and --

DR. YARSKY: But, fortunately, these effects all kind of start to compensate and we wind up with just a relatively narrow range of PCT.

CHAIRMAN MARCH-LEUBA: So the conclusion is this new FAST approach and using the right HGAP is probably recommended.

DR. YARSKY: Oh, absolutely.

CHAIRMAN MARCH-LEUBA: Yes, so that's a lesson learned.

MR. STAUDENMEIER: Joe Staudenmeier from Office of Research. One comment is, if you had 100-percent bypass plant, you might see a cleaner correlation between these PCTs and gap conductivities, but you also have the SRVs opening and closing. And sometimes it's a bit of randomness how the SRV opening lines up with an oscillation and causes it timing, it causes it to take off, so that's --

CHAIRMAN MARCH-LEUBA: Yes, I understand that.

DR. YARSKY: Oh, yes, yes.

MR. STAUDENMEIER: -- behavior in here that --

DR. YARSKY: You can see that very clearly when you talk about the timing of the peak PCT. So if we go back to my other presentation, I said PCT can occur anywhere between, like, 100 and 150 seconds. It's when you start layering on this SRV cycling you have these kind of, like, random points where if an oscillation lines up with an SRV bump, that's going to be the point where you get PCT. But it's like anywhere in this window of failure to rewet all the way up to the point where you have operator intervention, and anywhere in there, once those two effects line up with each other, boom, that's what is going to give you the PCT. So it's the timing looks much more scattered than the actual values of the PCT.

I realize I'm presenting here a table for the wrong case of PCT, so these values, we'll talk about these values because this is a case 2-1 as opposed to the reference case, but this figure is the reference case. And this is showing just for all of the different HGAP values what the PCT trajectories look like. And you can see, in certain cases, this early on between, so, like, 50 and 75 seconds there's this difference in the timing of the initial significant heatup. And so there's an effect that PCT has on, essentially, like the dryout/rewet cycling part.

CHAIRMAN MARCH-LEUBA: Okay. Because it's T01, T02, T03 out of the gap?

DR. YARSKY: Yes, so those are the different values. The T01 is the smallest value, and T10 is the highest value. And what I've marked here in red, T03 is the bold red graph, that's the highest PCT and that's the reference results that we talked about in the previous --

CHAIRMAN MARCH-LEUBA: Yes, but if you close your eyes and look at it, they're all the same.

DR. YARSKY: They're all the same, and they're all the same because once you have failure to rewet and you sort of continue to be in that failure to rewet condition during large-amplitude power flow oscillations, you wind up in the same place.

CHAIRMAN MARCH-LEUBA: And the difference in timing is what --

DR. YARSKY: The difference in timing,

it's just kind of random. You can see in all these curves it goes up and down. There's this effect of the SRV cycling and the powers unstable and the flow is unstable, so it wiggles.

CHAIRMAN MARCH-LEUBA: I'm squinting my eyes.

DR. YARSKY: Anywhere in that window --

CHAIRMAN MARCH-LEUBA: I'm closing my eyes a little bit and I see only one line.

DR. YARSKY: Right. Exactly. So we did this large variety of HGAP studies to account for, I would say, a crude aspect of, the crudeness of the fuel thermal-mechanical modeling that we're doing, but what we have found is that it doesn't, it has an effect, it doesn't have a significant effect, and we're just going to pull the most conservative one. You know, all these things have very similar behavior in terms of major trends and overall consistent PCT with only about, like, a 200F.

CHAIRMAN MARCH-LEUBA: And I'm going to say something to see if you agree. The plateau, I mean, where the temperature is higher between, say, 90 and 150 is controlled by the heat transfer coefficient that you use for film boiling.

DR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: In that one, we have some confidence on it. I know Joy is going to jump to the microphone right now. How confident are we on that value?

MR. STAUDENMEIER: The typical values for uncertainty at heat transfer coefficients is like 10 to 20 percent would be good, I'd say.

CHAIRMAN MARCH-LEUBA: I mean, you have some experiment other than to, that would be the number one parameter that would make my number go over 21.

MEMBER REMPE: So I am kind of curious. It's probably not that important, but I believe, if I'm looking at my colors correctly, that T05 behaves differently. It doesn't have a second peak at around 300 seconds. Am I correctly interpreting the colors? It just kind of goes down. Is it going to go up later and it just is timing, or what happened there? Because it's kind of a mid-range HGAP.

CHAIRMAN MARCH-LEUBA: You can use the mouse if you want to point.

DR. YARSKY: Oh, yes. So you're talking about this one --

MEMBER REMPE: Beyond the 300 seconds and it's obvious that one of those --

DR. YARSKY: Oh, one of these is on a downward --

MEMBER REMPE: Yes, what happened there? Because that's a mid-range. Isn't that the blue one and it's T05?

DR. YARSKY: Yes, this is --

MEMBER REMPE: I just am curious what happened. I mean, you said I can close my eyes and they're all the same curve, but that one is not.

DR. YARSKY: What I suspect is going on here, we would have to go back and look at the specific transient results. We didn't analyze all of these in detail, just the most limiting ones. What I suspect happens here is that the level hasn't dropped to top of active fuel plus 90 inches yet. And so the operators haven't started the feedwater restoration.

MEMBER REMPE: Okay. So it will go up later --

DR. YARSKY: Yes. I think what has happened here is it's taking longer for the level to decrease by a little bit in this case. But we could --

MEMBER REMPE: And maybe it's, again, the relief valves or something weird, but it's kind of weird because it's like mid-range, it's an HGAP of 15 and 12 and 18 behave the same. So there's some interesting --

DR. YARSKY: Well, I think what we found is that you don't see a consistent trend. So sometimes PCT will go up from one HGAP value to the next, and sometimes it goes down. But there are these competing elements that are affecting timing of the initial significant heatup and then, during the failure to rewet stage, you have a random element there, as well. So I think the conclusion overall is still that PCT, which is dictated by this first peak, is going to be in a range of about 200F and the timing is going to be in that window between failure to rewet to operator action time.

CHAIRMAN MARCH-LEUBA: Sorry. This question is for Joe again. You should sit closer to the microphone. During that period, between 100 and 150, do we have radiation cooling or it's just conduction? Did you have radiation cooling?

MR. STAUDENMEIER: Well, these are down where there's a lot of water, so there's no rod-to-rod radiation.

CHAIRMAN MARCH-LEUBA: Yes, but is the --

MR. STAUDENMEIER: I mean, radiation is included in the heat transfer coefficient.

CHAIRMAN MARCH-LEUBA: But this is an unusual case where you have a lot of cold water close to the rod, but there is a small film --

MR. STAUDENMEIER: Yes, in film boiling, I mean, yes, down in this range at the high oscillations, I think, based on what we've seen, we're probably under-predicting heat transfer coefficients. And I've done some studies looking at different film boiling models. I mean, all the studies I've done with lower temperatures, transition boiling is another thing that these things are sensitive to. So converted film boiling, transition boiling, you know, it's sensitive to that.

CHAIRMAN MARCH-LEUBA: My gut feeling when I'm looking at this is this is an upper bound, this is a conservative number. When you have so much cold water in the flow that you probably have higher heat transfer than what you're using.

MR. STAUDENMEIER: Well, it's more, yes, it's probably more with our taking into account turbulent heat transfer for the higher flow velocities. Our data that we have that our inverted annular flow model is based on is of lower flow velocities. We have some higher flow velocity data or mass flux data that we tend to under-predict the heat transfer for those cases. So our model is designed more for PWR reflood heat transfer, and if you get up into these mass fluxes you would get better heat transfer than what our model would predict, and some studies done looking at some changes to the model have confirmed that.

CHAIRMAN MARCH-LEUBA: I'm looking at this from a safety point of view, and we don't have that much margin to 2,200.

MR. STAUDENMEIER: Well, I mean, for peak rods maybe you don't. For average rods, you'd be down a lot lower. So in ATWS, I mean, when the ATWS rule went into place, there was fuel damage that was considered as part of that and it's a combination of frequency and fuel damage and it's really just shutting down the reactor. You're still going to maintain core coolability even on the hottest rods.

CHAIRMAN MARCH-LEUBA: The core coolability of fuel rods. But what I'm trying to get to is, even though we don't have that much margin, this is likely to be a conservative calculation because there are other, the heat transfer is likely going to be --

MR. STAUDENMEIER: I believe it's conservative based on the models in our code. The

Tmin model that Pete is using --

CHAIRMAN MARCH-LEUBA: It's also conservative.

MR. STAUDENMEIER: -- is a conservative Tmin model compared to what we would think is more realistic.

MEMBER CORRADINI: So, Joe hold on a minute. So, I want to make sure I understand that when you said that core coolability is maintained, what is that judgement based on?

It's not based on the peak rod only. Because the peak is close, and if I had my uncertainty gurus in the room, they would come after you about you would have to do the uncertainty range.

Which, I would think if I did it, I would essentially get -- could get about 22 hundred. So it's not the peak rod.

How are you determining then core coolability of the peak rod is close, but the average of that is far away? That's what I -- Joe said something and I want to make sure I understood how you got it.

MR. YARSKY: Yeah. We're using as our criterion 22 hundred as our fuel damage criterion. But this is beyond design basis event.

So there's no consideration of uncertainty.

MEMBER CORRADINI: Okay. So, that's the going in approach.

MR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: But what we've done in the past is even if a few -- even if a hundred pins in the whole core were to run, that would not compromise core coolability.

MEMBER CORRADINI: Well but what I'm -- I don't disagree with you. I want to know what they're thinking --

CHAIRMAN MARCH-LEUBA: Yeah.

MEMBER CORRADINI: About what he just said. If it's one, if it's ten, if it's a hundred, we're still okay?

MR. YARSKY: Like right now research I don't think is in a position where we could rely --

MEMBER CORRADINI: We can always default to NRR and make that.

MR. YARSKY: Well, we could reliably calculate a damage population. So we would need to have some more advances, I think, in our methods before we could say that the population of damaged fuel rods is some number.

MEMBER CORRADINI: So you're going where?

MR. YARSKY: Right. So we're able to like layer some conservatives -- conservatisms peaking factor rod groups. And then we can calculate what we think is the PCT.

I would say we needed to do a little bit more with our methods before we can say two percent of fuel is damaged or something.

MEMBER CORRADINI: Okay. Well, I guess I'm not so much asking that as that kind of Joe stepped into it when he mentioned core coolability. But your going in approaches what I'll call a conservative analysis of the peak clad temperature.

MR. YARSKY: Um-hum.

MEMBER CORRADINI: And if that still meets the criteria, then you're okay.

MR. YARSKY: Right. Exactly.

MEMBER CORRADINI: Okay.

MR. YARSKY: Exactly. So, it's -- we don't have to answer these more complicated questions about how much of the core remains coolable or noncoolable.

If there's fuel damage if the PCT remains below 22 hundred up. And then we can say there is no fuel damage.

MEMBER CORRADINI: Okay. Fine. Thank you.

CHAIRMAN MARCH-LEUBA: Yeah, I mean it's not severe for damage.

MR. YARSKY: Well, to compare and contrast fuel failure with fuel damage. Which mean different things.

CHAIRMAN MARCH-LEUBA: Yes.

MR. YARSKY: Certainly there will be cladding perforation.

CHAIRMAN MARCH-LEUBA: For others, for AOOs, see a chip would be considered a fuel failure.

MR. YARSKY: Would be a fuel failure.

CHAIRMAN MARCH-LEUBA: Yeah.

MR. YARSKY: Right. So there is certainly failed fuel. But not damaged fuel.

CHAIRMAN MARCH-LEUBA: Okay, failure versus damage.

MR. YARSKY: Right. So damage versus failure. Yeah, but certainly we've shown that there are pins that go into extended dry out. So the perforation would be expected.

Okay. In addition to the reference piece, we also analyzed a case at a slower feedwater temperature ramp.

We refer to this as like the updated TRACG analysis rate. So analysis were initially performed at 1.3 Fahrenheit per second feedwater temperature decrease.

And then the sensitivity study is performed at a slower feedwater temperature decrease of 0.5 Fahrenheit per second.

And this Figure here is just showing the difference in terms of the feedwater temperature. And we call this case, Case 2-2.

So in Case 2-2, slower feedwater temperature decrease. The immediate effect of the slower feedwater temperature decrease is that the subcooling transient is less severe with a slower feedwater temperature ramp.

So you can see in Case 2-2, which is the sensitivity, is that the peak core inlet subcooling is lower. This has an effect, the early transient is pretty much essentially the same.

Differences are difficult to see once the reactor becomes unstable. But after about like one hundred seconds on this plot, you can see it's easier to see that the average power is slightly higher in the base case relative to Case 2-2.

And this is just a function of feedwater temperature impact on the core inlet subcooling. And we can see here is a comparison of the PCT.

And the PCT heat up in the slower feedwater temperature cases is slightly earlier. But in the higher -- in the faster feedwater temperature decrease case, the peak inlet subcooling is higher, the core power is higher, and you get a higher PCT in that case relative to those slower feedwater temperature decrease.

This difference in the timing of significant heat up I will not focus too much on. Because these -- what we've pooled is the worst case from the HGAP sensitivity study.

So these are not performed at the equivalent value of HGAP. We just are always pulling the worst case from all the values in HGAP.

So, some differences in the timing here expected. And it can be attributed to the difference in HGAP value.

But, I mean, the result here is not surprising is that at a slower feedwater temperature ramp, the PCT is lower.

The timing of heat up is slightly different between the two cases is about ten seconds. This occurs during the unstable phase.

And what I'm showing here is just the marking in times with blue for Case 2-2 and red for Case 1. So, blue is the slow feedwater temperature ramp. And red is the original case.

Timing here wise where the initial significant fuel heat up occurs between the two cases when it's occurring during the unstable phase. So we think this is just a combination of nonlinear effects and the fact that there's just different -- each got values different subcooling.

Is that the best in time will be different between these two cases. But it's a combination of a number of effects.

If we look at the candidate hot channels, so this is the average run in a candidate hot channel. Then we compare the original case to the sensitivity case, we can see that they are in closer agreement in terms of the point where the average rod heats up in the candidate hot assembly.

And that the general trends and behavior are in closer agreement. But you can see this significant effect it has in terms of the PCT. And then it's like lower for the lower feedwater temperature case.

And so this Table here is providing

information for all of the HGAP values that we looked at in terms of a PCT, time of PCT, and time of this initial heat up as a function of the HGAP values.

And what the figures we've shown are just for the maximum PCT. Which here was for an HGAP value of 12 kilowatts per square meter Kelvin.

So moving on, we also looked at operator action timing. So this is what we call Case 2-1.

Case 2-1 also has the slow feedwater rate. But has operator manual action to control level. It occurs at 96 seconds instead of 120 seconds.

So that would be a 106 seconds problem time. The rationale here if this is 80 percent of 120 seconds and is a metric used by the licensee with respect to their operator training program.

So it's --

MEMBER REMPE: Can you elaborate on that? Because I guess I haven't seen that in what I read for tomorrow.

What do you mean it's a metric?

MR. YARSKY: Could I defer that to tomorrow? Because I'm not really versed in --

MEMBER REMPE: Okay.

MR. YARSKY: The operator action, the basis for this operator action.

MEMBER REMPE: Because I saw a value in their open slides that said that, I don't know, that some percent got 85 seconds instead of 120. But I wasn't sure what the metric is.

And they can answer it tomorrow. But I just am curious what's going on with all that.

MR. YARSKY: Yeah. From the research perspective there was an analysis submitted by the licensee that was done at an operator action having a 96 seconds.

MEMBER REMPE: Um-hum. Okay.

MR. YARSKY: And if possible, I'd like to defer further discussion to tomorrow.

CHAIRMAN MARCH-LEUBA: But the bottom line is, when you train a crew in the simulator, if they don't make it in 120 seconds they fail.

MEMBER REMPE: Right.

CHAIRMAN MARCH-LEUBA: Because that's the metric.

MEMBER REMPE: But well they gave a value of 85 seconds. And we can hear tomorrow I guess. But I just was curious.

MR. BORROMEO: Well, this is Joshua Borromeo, NRR. The 80 percent is where the licensee will start analyzing more why the operator action was longer then 80 percent.

So they really shoot for 80 percent. They're not shooting for 120 seconds. They're shooting for 80 percent of 120, which is 96 seconds.

So that was really the basis of why we asked the licensee to provide a 96 second sensitivity study. And why we had the research take a look at it as well, because, you know, we didn't know what the research results were going to be whenever we asked them.

So, we wanted to figure out what was closest to reality. And possibly gain margin back if necessary.

MR. YODERSMITH: My name is Stephen Yodersmith from the Brunswick Nuclear Plant. And so the 80 percent in our time critical operator action procedure, the procedure drives you to meet 80 percent.

If you don't meet 80 percent then Josh is exactly right. You've got to enter it in the corrective action program.

Maybe train the operators some more. That's the target for training, is 80 percent of your time critical operator action time, which is the 120 seconds.

I believe in our analysis we presented some results that said it was 85 seconds was the average time that our operators took. So on average for the times that we took for the scenarios that we did for MELLLA+, it was 85 seconds was what we met.

Eighty percent is the -- or the 96 seconds which is 80 percent of 120 seconds, is the target in training. So you can be a bit more conservative then the way operators typically perform.

CHAIRMAN MARCH-LEUBA: And is that 80 percent for each crew? Or the average of the crews?

MR. YODERSMITH: That's 80 percent for each crew.

CHAIRMAN MARCH-LEUBA: Okay.

MR. YODERSMITH: Yep.

MEMBER REMPE: Thank you.

MR. YODERSMITH: Yep.

MR. YARSKY: Okay. So this Case 2-1 now is a combination of more rapid operator intervention timing and a slower feedwater temperature rate. So this is a less limiting or less severe combination of parameters.

The first Figure here on the left is showing the feedwater temperature rates, is very similar to the Figure we showed for Figure 2- -- for

Case 2-2. Similarly there's a difference in the peak inlet subcooling, which is higher in the base case.

However, with the earlier operator intervention what you can see in the second figure, the one on the right, is that the subcooling begins to decrease earlier. This is absolutely expected with the earlier termination of the feed injection.

The core power responses, if we were to compare Case 2-1 and Case 2-2 are very similar. With core power being lower -- where core power is lower owing to the lower subcooling when compared to the base case.

And the power decreases earlier in Case 2-1 because of the earlier decrease in the reactor water level. If we look at PCT, the PCT is actually the same in Case 2-2 as it is in 2-1.

And that's because the PCT occurs around 80 seconds. Which is before the start of the manual operator action.

So the manual operator action doesn't affect the PCT result. However, the PCT starts a downward trajectory earlier, which is expected because of the earlier operator action.

MEMBER CORRADINI: So, I have a question. I know I shouldn't care about numbers, but I'm looking at the three tables, conductivity, sensitivity -- conduct and sensitivity, slow ramp rate sensitivity, and level control sensitivity.

And a lot of the numbers are identical.

MR. YARSKY: Yes.

MEMBER CORRADINI: Help me here.

MR. YARSKY: There's a mistake in the slide, and I apologize for that. On slide three, and this is presenting the results for Case 2-1 instead of Case 1.

MEMBER CORRADINI: Good. That makes me feel a whole lot better. Because they were identical. And I didn't understand that.

MR. YARSKY: So, that's our mistake. In the report which you guys should have received, there's the Table. If not I'll make sure that the Committee gets copied on the report.

MEMBER CORRADINI: That's fine. You solved my problem. Okay.

MR. YARSKY: However, when we get to the last Table that I show, in Case 2-1, where some of these values are exactly the same, but not all of them, compared to Case 2-2 they should be.

Because the PCT occurs in certain cases before 106 seconds. So if the time of peak PCT is before 106 seconds, then the value should be exactly the same.

MEMBER CORRADINI: Okay.

MR. YARSKY: Okay. So hopefully that -- so that's a mistake on slide three.

MEMBER CORRADINI: You've helped me. Thank you.

MR. YARSKY: Okay.

MEMBER REMPE: However, you said something that I was going to ask at some point. That there is a report, I think it's referred to as Reference 30 in the plug in.

And I would like to see a copy of it, the documents, your calculations. Because right now all we have are the slides and the plug in.

MEMBER CORRADINI: We got the report. It's called the plug in report.

MEMBER REMPE: We got --

MEMBER CORRADINI: We got the report.

MEMBER REMPE: We got a plug in for the draft SE. But in that plug in they reference something called Reference 30.

Which I bet is a document that goes with these new graphs that you did, right?

MR. YARSKY: There is a document that goes with these drafts.

MEMBER REMPE: Yeah.

MR. YARSKY: We can make sure --

MEMBER REMPE: And we don't have that.

MR. YARSKY: We can make sure that the Subcommittee gets it.

MR. BORROMEO: Reference 30 is the research report --

MEMBER REMPE: Right.

MR. BORROMEO: That has all these plots in. And I have that paper copy right here.

MEMBER REMPE: Yeah. And again, we have not seen that. Correct?

CHAIRMAN MARCH-LEUBA: Microphone, please.

MS. ABDULLAHI: Sorry. We have both. All the slides except for the new different slide. And we have two reports based on the user need of NRR that research has to do.

MEMBER REMPE: And did we get those? I did not.

MS. ABDULLAHI: They should be posted either in the G Drive, or their G Drive as well as SharePoint.

MEMBER REMPE: I did not see them. And I will go look right now. Actually I know it's not on the SharePoint.

And I actually though I went to the G Drive too. Did you get it Jose?

CHAIRMAN MARCH-LEUBA: No. I don't remember seeing it.

MS. ABDULLAHI: Remember I got the slides from them. From NRR, here's the one I transferred right away to you.

MEMBER REMPE: Right. The slides I got. But I never got the -- anyway, we would like to see that. But I'm looking right now because I don't think we got it.

So, please someone makes sure we have it.

MR. YARSKY: Yeah. We will make sure that you guys get the report.

CHAIRMAN MARCH-LEUBA: You give Zena a memo number so we can get it. Or just a copy of the report.

MEMBER CORRADINI: We'll do it later. Let's do it later.

MR. BORROMEO: Yeah. This is Josh Borromeo from NRR. The supplement or the addition to the SE that you guys got is a summary of what recently was done.

MEMBER REMPE: Right. That's all we see.

MR. BORROMEO: So, you know, I looked at a lot of the same works. So, it should read similar.

MEMBER REMPE: Yeah. Okay. Okay, thank you. And it's not on the G Drive. So, please make sure.

MR. YARSKY: We'll make sure that you get it.

Okay. Well, that's everything I have for the open session. So we can -- if we are to proceed to the next presentation, we'll have to close the session.

CHAIRMAN MARCH-LEUBA: Okay. So at this point, even though the agenda says to it 10:30, we are going to ask the comments from the public before closing the session.

Anybody in the room? And let's make sure the phone line is open.

MR. YODERSMITH: I just wanted to make one clarifying point.

CHAIRMAN MARCH-LEUBA: Go ahead and say who you are.

MR. YODERSMITH: Stephen Yodersmith from Brunswick. And I just wanted to clarify something. And that way when you present it -- when we present to you guys tomorrow there won't be any confusion.

On the BSEP unit differences presentation, our rated core form in both units is 77 million pounds per hour. And so there is a difference in the max core flow we can achieve on each unit because of the bypass -- sorry, because of the orifice size difference on each unit.

So that the max core flow we can achieve is different, however rated is 77. And for MELLLA+ we're asking for 85 percent of 77.

So, I just wanted everybody to be on the same page when we throw up a unit independent power flow map tomorrow. I didn't want there to be any confusion about that.

MEMBER REMPE: Because I was confused on the power flow map that's in the draft SE. And I was wondering about that.

So thank you.

MR. YODERSMITH: Yeah.

CHAIRMAN MARCH-LEUBA: Is it safe to assume that the calculations, the continued calculations use a higher draw line because they use the lower flow?

MR. YODERSMITH: So the --

CHAIRMAN MARCH-LEUBA: Do you review what power and flow they use for the staffing conditions?

MR. YODERSMITH: I don't know --

MR. YARSKY: Our power flow calculations are conservative relative to the licensee submittal.

CHAIRMAN MARCH-LEUBA: Higher online?

MR. YARSKY: Higher online.

CHAIRMAN MARCH-LEUBA: Okay. And I'll ask you tomorrow what so you have.

MR. YODERSMITH: Yeah.

CHAIRMAN MARCH-LEUBA: What maximum flow can you reach on both units?

MR. YODERSMITH: So, we're licensed on both units to the 80 and a half million pounds per hour.

CHAIRMAN MARCH-LEUBA: Which is 105?

MR. YODERSMITH: Which is 104.5 percent.

CHAIRMAN MARCH-LEUBA: Yeah. Can you get there?

MR. YODERSMITH: On Unit One we can. On Unit Two we can't really get there due to the emphasis.

CHAIRMAN MARCH-LEUBA: Power, yeah. Okay. Thank you.

MR. YODERSMITH: Yes, sir.

CHAIRMAN MARCH-LEUBA: So, any more comments from the room?

(No response)

CHAIRMAN MARCH-LEUBA: I believe the phone line is open. If there is any person on the phone line that wants to make a comment?

(No response)

CHAIRMAN MARCH-LEUBA: I'm not hearing anybody. We are going to go into closed. Maybe a break before the closed session.

We are going to go into a short recess. And we'll be back at -- how should you want it? Yeah, let's come back at 10:50. Yeah, ten til the hour.

(Whereupon, the above-entitled matter went off the record at 10:37 a.m. and resumed at 11:30 a.m.)

CHAIRMAN MARCH-LEUBA: So, we are off the closed session. We're back in open session.

And GE is still on the line, on the same line. Somebody just dropped off.

MR. HECK: Charles Heck, GNF here. Should we call in on the open line now?

CHAIRMAN MARCH-LEUBA: We'll keep you on the closed line if you don't mind.

MR. HECK: Very good.

CHAIRMAN MARCH-LEUBA: Both of them will remain open.

MR. HECK: Understood.

CHAIRMAN MARCH-LEUBA: Okay. I think we have the open line open now. You can go and conclude your speaking.

MR. YARSKY: Okay. Thank you. And this final part of the presentation is just to summarize the conclusions from the staff confirmatory analysis.

We presented the results of three Cases. Of these, Case 1 represents the worst combination of feedwater temperature and manual operator action timing.

And we analyzed this at a variety of HGAPs and picked the worst value of HGAP. And we found was that the PCT remains below 2200 in the worst combination.

The PCT in that case was 2,109 degrees Fahrenheit. The Case 1 results confirmed the effectiveness of manual operator actions, i.e. lowering the level and injecting boron through the standby liquid control system to suppress oscillations and bring PCT in a downward trajectory.

In Case 1 the PCT was not very sensitive to HGAP. And values ranged between about 1,900 and 2,100F.

We also found is that TRACE may under

predict condensation heat transfer as it relates to the feedwater flow being injected into the steam space above the liquid level in the downcomer late in the transient once operators restore feedwater flow to control level.

This under prediction is related to the use of the level tracking model in TRACE, which fixes the interfacial heat transfer based on the geometry.

However, limiting the condensation heat transfer will be conservative with respect with the impact it has on the subcooling late in the transient. So it doesn't impact our conclusions with respect to the PCT.

In some of our calculations we have a higher then expected jet pump flow asymmetry very late in the transient. The slide says that the exact cause for this asymmetry is not known. But we figured it out.

So very late in the transient there can be one jet pump having a slightly higher flow then the other jet pump. This is due to if you have cold water stacked on top of hot water, it's like naturally unstable.

So the cold water has to come down in one sector relative to the other. Which can cause a small asymmetry in the jet pump flow rate at the late transient once the feedwater flow is reestablished.

But this has no impact on the PCT results. And then in terms of the sensitivity studies that we've done for feedwater temperature reduction rate and for earlier level reduction, we found of course that a slower feedwater temperature rate and earlier operator intervention result in a milder transient. And result there for in a lower PCT.

And lastly, all of our cases indicate margin to fuel damage where we're using 2200F as a criterion to indicate whether or not there's any fuel damage. In the case of 120 second operator action, that slow feedwater temperature decreases 0.5 Fahrenheit per second.

We were kind of able to compare TRACE and TRACG on an apples to apples basis. And the PCTs agree relatively well with differences being attributed to differences in the calculation that we can understand.

In Case 2-1, TRACE predicts a much higher PCT. That's because the instability is completely avoided in the TRACG calculation.

And that's everything that I have.

CHAIRMAN MARCH-LEUBA: Okay. So we

already went to comments earlier. But I will allow the floor to be open again if anybody wants to make a final comment.

And people on the line, I'm not sure that earlier when I called for comments your line was unmuted. If anybody from GE wants to make a final public comment on the public, the open session, you are welcome to do it now.

Okay --

MR. HECK: This is Charles Heck from GNF. I wanted to make a comment on two points. One is that the under prediction of the condensation and heat transfer as Dr. Yarsky has said, is conservative.

But it also helps explain why the core power remains somewhat higher in TRACE. Because it increases the subcooling.

So, I think those results are completely consistent.

MR. YARSKY: Oh yeah. Charlie, absolutely.

CHAIRMAN MARCH-LEUBA: Okay. Thank you.

MR. HECK: The other comment I wanted to make was from this morning's open session. And it's related to multiple statements that were -- refer to the basis for the Tmin model, which is the homogeneous plus contact temperature.

And there was an inference to the data that's being used for that. And my comment is with regards to this publically funded data, I was wondering, is there any time scale for when that data will be made available to the public?

CHAIRMAN MARCH-LEUBA: Charlie, unfortunately the rules don't allow us to answer your questions at this moment. But you can contact Zena separately and she'll let you know use of that.

But right now you are on the -- we're on the comment section, not on the question section. So, sorry not being able to tell you that.

So, we're going to close the line. And I mean, unless anybody else has more comments? I'm going to go around the room.

Mike, do you have any?

MEMBER CORRADINI: No. No, I don't have any further comments. I just thank the staff.

CHAIRMAN MARCH-LEUBA: Joy then?

MEMBER REMPE: I also want to add my thanks. I think it's important to have a good feeling especially with the complexity with this LAR about the margin.

And I think that the code, even though

it's identified some errors where you need to keep working, it's giving us that confidence. And so I appreciate you guys doing it and being able to discuss it today.

CHAIRMAN MARCH-LEUBA: Yeah. I also want to thank you. I think it was a month or two months ago we were ask -- talking about whether we should have this session, or just bundle it up with Brunswick tomorrow.

And I think it was a good idea to do it now. Because we had a more fine technical discussion with the people that are actually interested in listening to it, instead of the whole committee.

You wanted to say something?

MR. YARSKY: Oh, no. Absolutely, thank you for the committee for having us. And we're always happy to talk to you about the work that we're doing.

CHAIRMAN MARCH-LEUBA: And I'll put -- let me put again the plug for continued analysis. Computer analysis are slow, and put a drag on the review often. And they're expensive.

But, I think they're valuable. And from my point of view I keep talking about uncertainties of omission. The confirmatory analysis wouldn't have planned to use their results.

But we plan to see if they forgot something. Is there a cliff somewhere that they unlock it and get into it. And we've been making a mistake over it.

So, I would recommend that the staff does not completely eliminate confirmatories. While at the same time speeding them up. And so it would be more responsive to the needs of NRR and NRO.

With that, the session is closed -- is we are adjourning. Bye.

(Whereupon, the above-entitled matter went off the record at 11:39 a.m.)

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

INTRODUCTION

Dr. Peter Yarsky
US NRC Office of Nuclear Regulatory Research

AGENDA

1. Overview of Anticipated Transient without SCRAM with Instability (ATWS-I) in the context of Maximum Extended Load Line Limit Analysis Plus (MELLLA+) expanded operating domain
2. NRC Analysis Methodology
3. Brunswick Steam Eletric Plant (BSEP) Unit Differences
4. Analysis of Reference ATWS-I Scenario
5. Effect of Gap Conductance
6. Effect of Feedwater Temperature Transient
7. Effect of Operator Action Timing
8. Comparison to Licensee's TRACG Calculations
9. Conclusions

INTRODUCTION

- The Office of Nuclear Regulatory Research (RES) was tasked by the Office of Nuclear Reactor Regulation (NRR) to perform confirmatory analyses of ATWS-I for BSEP to support its review of the MELLLA+ license amendment request.
- RES staff used our suite of codes to perform this confirmatory analysis and today will present our base case analysis results and results from sensitivity studies that examine the effect of gap conductance, feedwater temperature, and operator action timing.
- At the conclusion, RES results from TRACE/PARCS will be compared with the licensee's results from TRACG.
- Some portions of this presentation will be closed to discuss proprietary information.

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

OVERVIEW OF ANTICIPATED TRANSIENT WITHOUT SCRAM WITH INSTABILITY

Dr. Peter Yarsky
US NRC Office of Nuclear Regulatory Research

MELLLA+ DOMAIN

Maximum Extended Load Line Limit Analysis Plus (MELLLA+) is an expanded BWR operating domain allowing high thermal power (120%) at low flow (80%)

MELLLA+ operation introduces new aspects to the progression of Anticipated Transient Without SCRAM (ATWS) events

SAFETY SIGNIFICANCE OF THE FCW

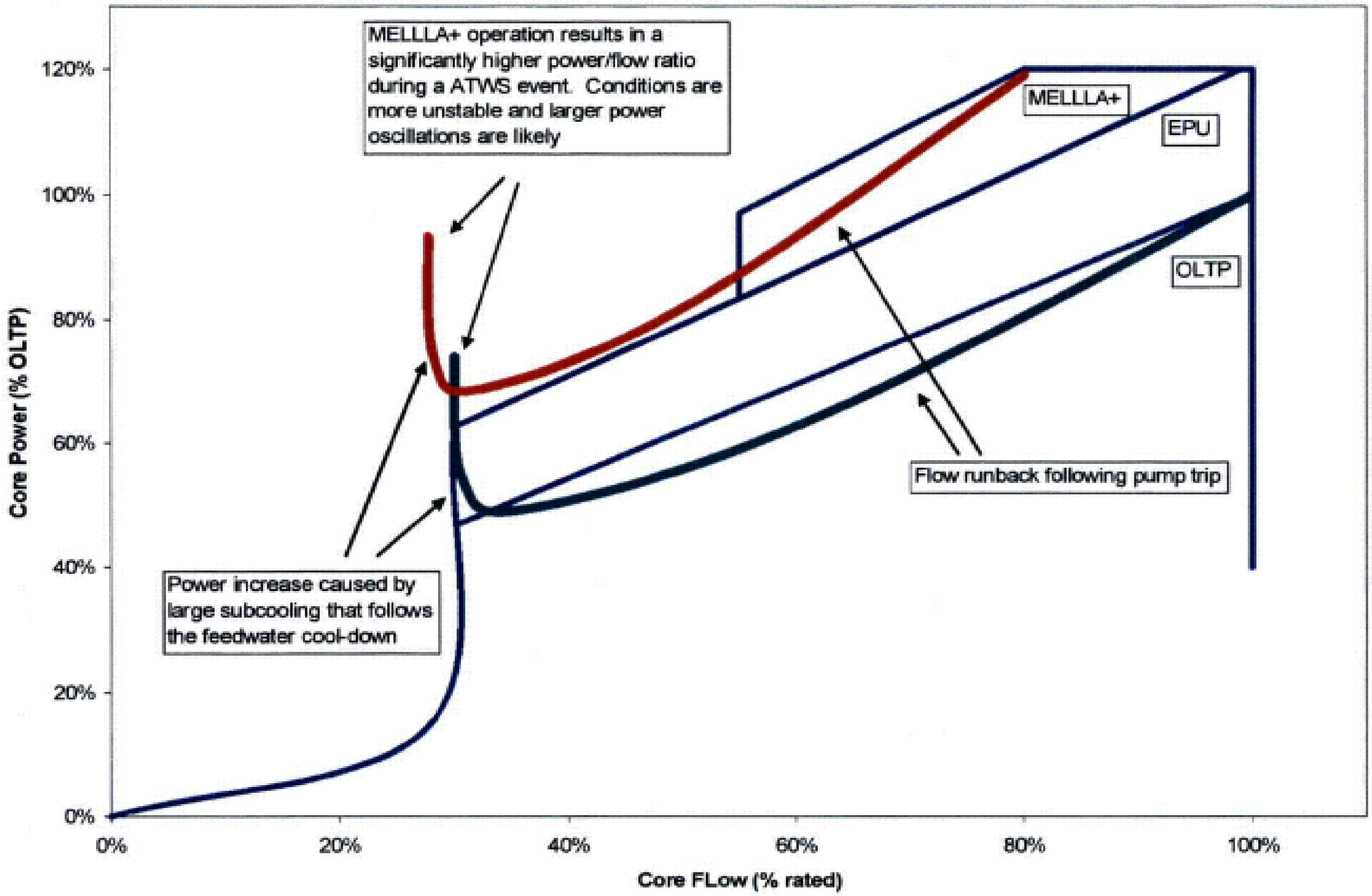
During ATWS events, the reactor power is decreased by a trip of the recirculation pumps (2RPT)

The power and flow decrease as the pumps run down

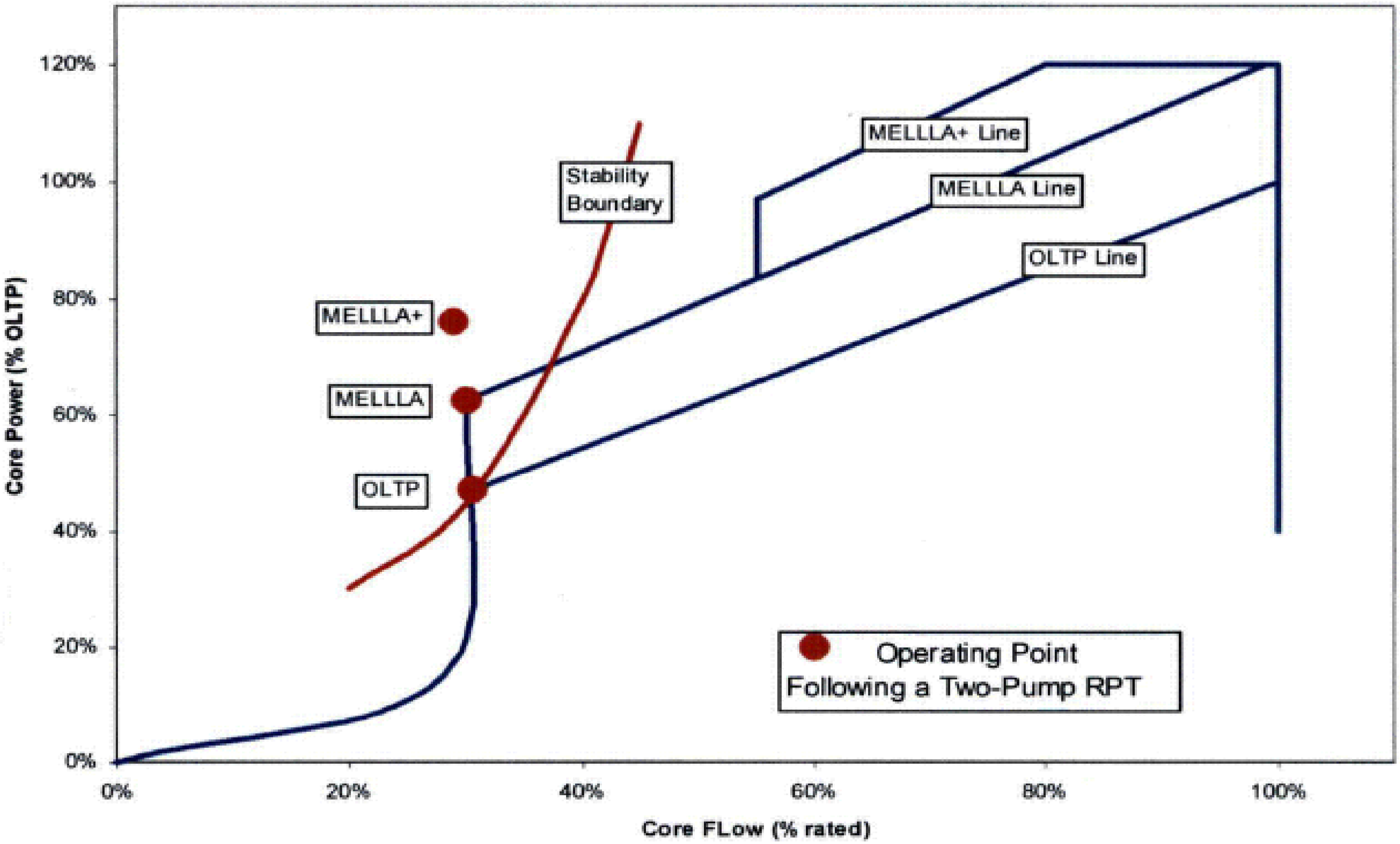
Power then increases due to a decrease in feedwater temperature

When the flow rate is low (80 %RCF), the 2RPT becomes less effective in the reduction of gross core power

OPERATING DOMAIN AND RPT



OPERATING DOMAIN AND RPT



OVERVIEW OF ATWS-I

ATWS event considered is a turbine trip event with turbine bypass capability (TTWBP)

The TTWBP results in a pressure pulse, a trip of the recirculation pumps, and a loss of extraction steam to the feedwater heater cascade

The TTWBP ATWS is expected to yield unstable conditions and large amplitude power instability

Operators control reactor water level and inject boron through the standby liquid control system (SLCS) to mitigate the event

PREDICTED FUEL HEAT-UP MECHANISM

Oscillation magnitude increases and the fuel undergoes periodic dryout/rewet cycling.

As oscillation magnitude continues to grow, the rewet period of the cycle becomes insufficient to remove all of the energy accumulated in the fuel during the dryout period. This is accompanied by a "ratcheting" of the fuel temperature upwards after each dryout/rewet cycle.

Once temperature ratchets up to the minimum stable film boiling temperature, the cladding surface "locks" into film boiling heat transfer.

Once locked in film boiling, and while reactor power is high, fuel temperature excursion occurs.

PLANT SPECIFIC CONSIDERATIONS

Fuel and core design

Turbine bypass capacity

Manual operator action timing

SLCS boron enrichment

Feedwater pumps (motor vs. steam driven)

Feedwater temperature transient

Automatic protective features (i.e., NMP2)

QUESTIONS

GENERIC PLANT ANALYSIS ATWS-I RESULTS

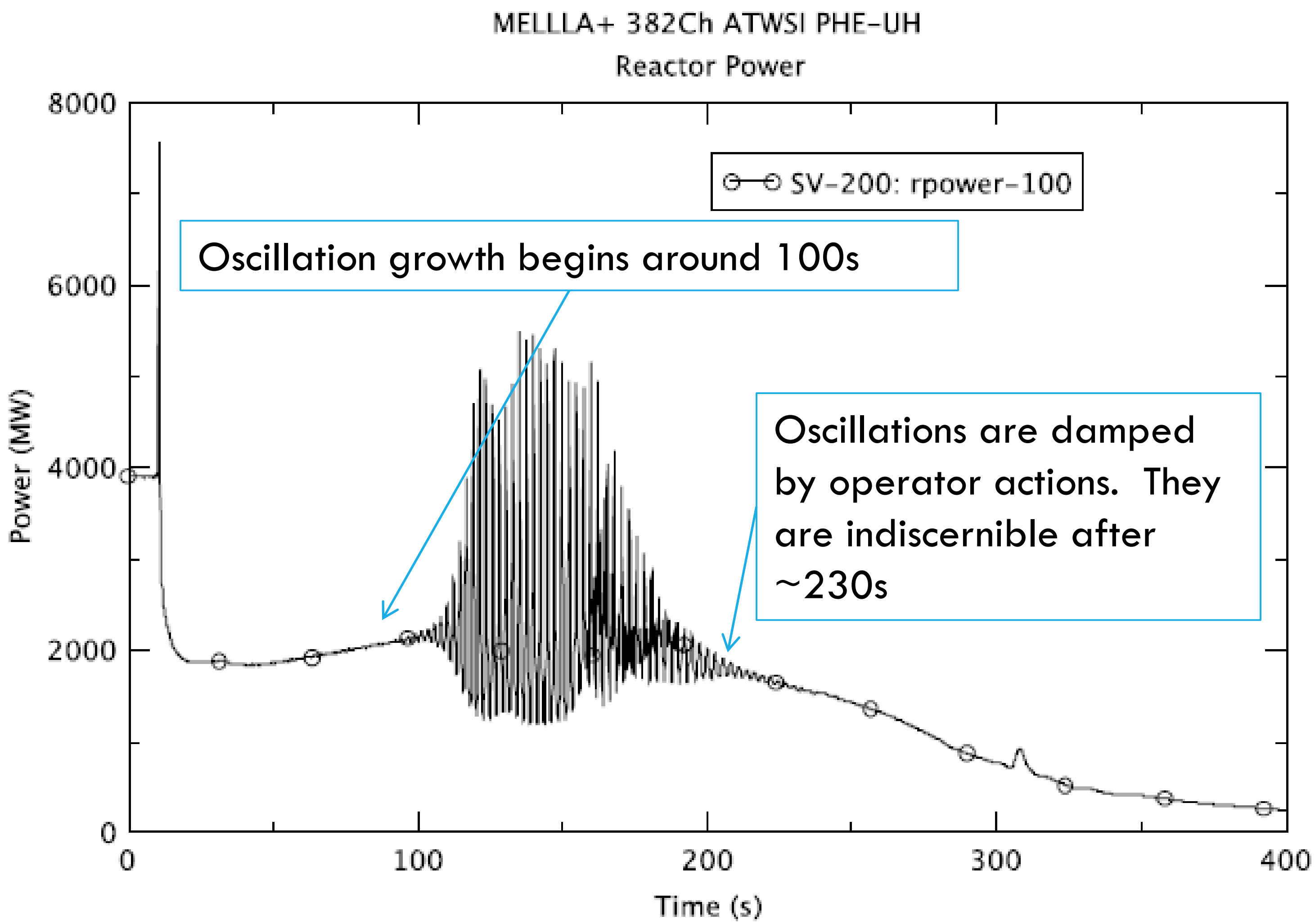
Representative Case:

- Generic BWR/5 model
- TTWBP with 100% bypass capacity
- Initial core flow rate is 85% rated
- Initial power is 120% of originally licensed thermal power (OLTP)
- Core exposure is peak-hot-excess (PHE)
- Operators attempt to control reactor water level to top of active fuel (TAF) starting 110 seconds into event
- Operators initiate SLCS at 120 seconds into event

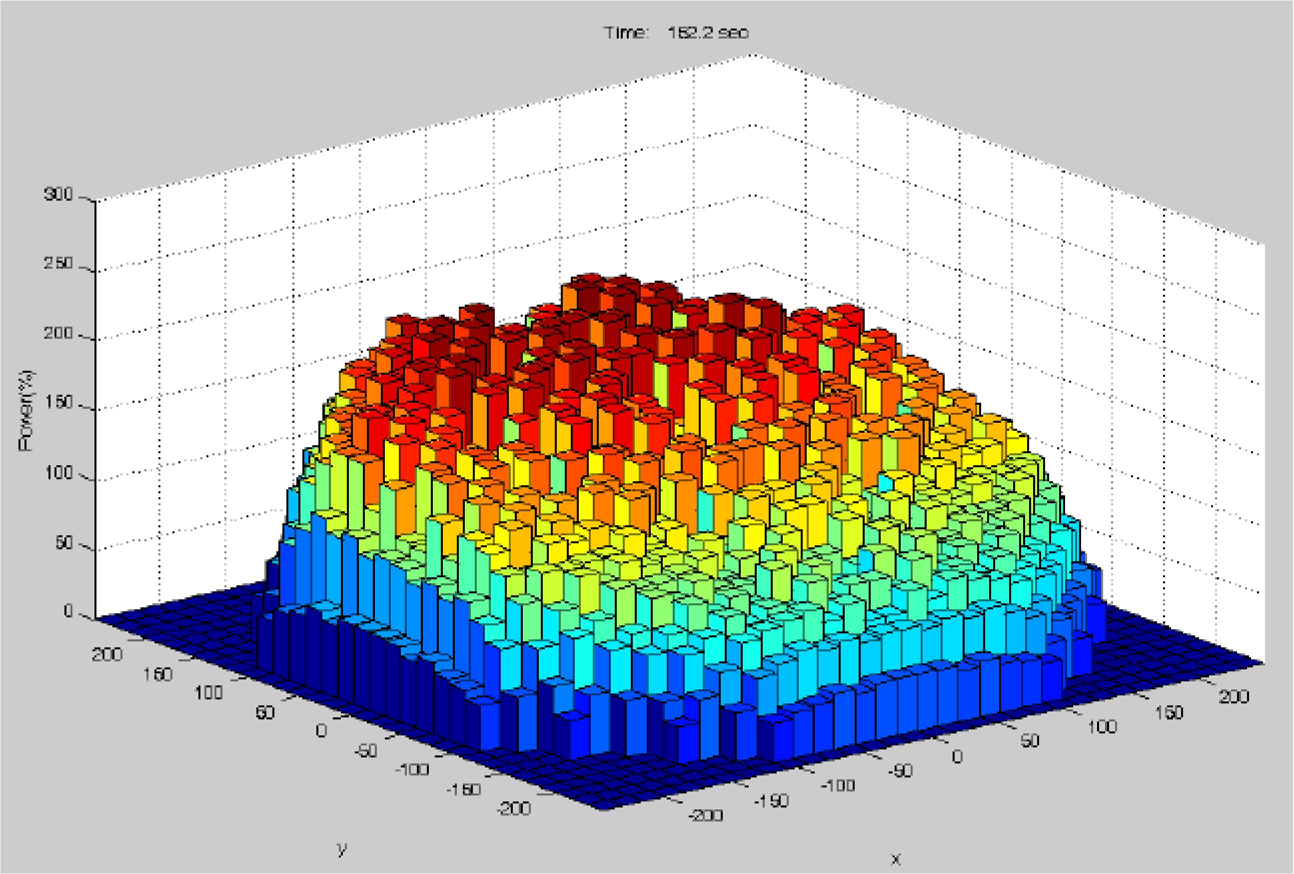
PHE ATWS-I CASE – SEQUENCE OF EVENTS

Time (s)	Event
0.0	• Null transient simulation starts.
10.0	• Null transient simulation ends. • Turbine trip is initiated by closing the TSV. • Recirculation pumps are tripped on the turbine trip. • Feedwater temperature starts decreasing.
10.1	• TSV closes completely and starts opening again to simulate 100% turbine bypass.
11.1	• TSV (bypass) completes opening.
~11.4	• Steam flow starts decreasing.
~12.3	• Feedwater flow starts decreasing.
~95	• Power oscillation (instability) starts.
120	• Water level reduction (WLR) is initiated by reducing the normal water level control system setpoint linearly to TAF over 180 s.
130	• Boron injection is initiated and linearly ramped to full flow at 190 s.
~144	• Bi-modal oscillation of the core power is initiated.
~160	• Boron starts accumulating in the core.
~163	• Downcomer water level begins decreasing. • Peak cladding temperature of ~1700 K occurs.
~240	• Power oscillation ends.
400	• Simulation ends.

TRANSIENT REACTOR POWER



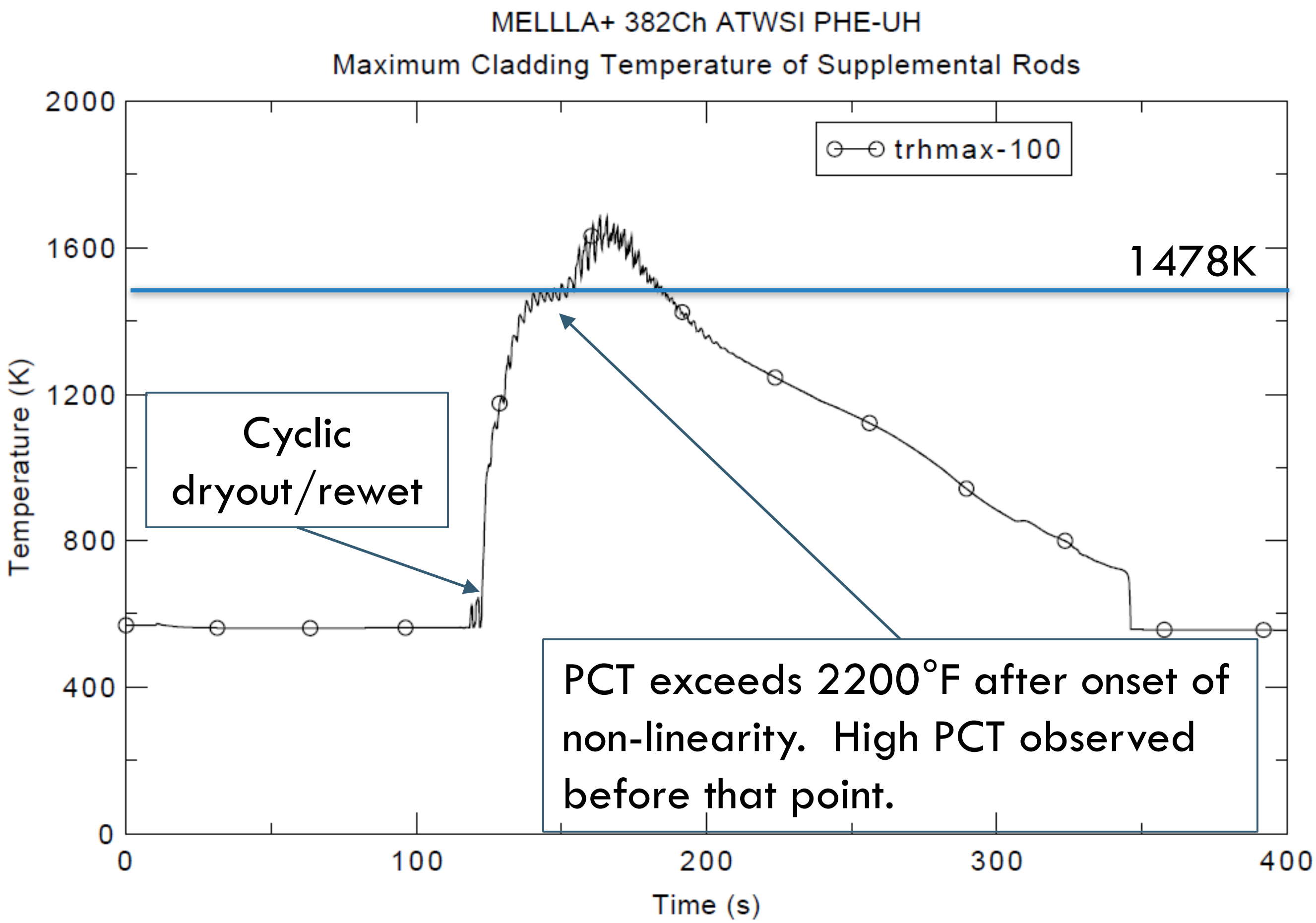
BI-MODAL OSCILLATIONS



VISUALIZATION

PHE – Case 2

PEAK CLADDING TEMPERATURE RESULTS



BASE CASE CONCLUSIONS

Point in cycle studies confirm that PHE is the most limiting state-point

- Large amplitude regional power oscillations develop (modal coupling with frequency doubling).
- High amplitude power oscillations (local) results in calculation of high PCT (~1700 K [2600 °F]).

Operator action to reduce level

- Effective in reducing FW flow, limiting increase in core inlet subcooling and eventually eliminating inlet subcooling.

Operator action to inject boron through SLCS

- Effective in suppressing power oscillations and reducing core power level.

METHODOLOGY OVERVIEW: CODES

TRACE

- TRACE simulates the thermal-hydraulic response of the plant and core

PARCS

- PARCS simulates the neutron kinetics in three-dimensions

SCALE/TRITON

- The TRITON sequence with NEWT calculates parameterized nuclear data

MCNP

- Coupled gamma/neutron transport calculations with MCNP establishes direct energy deposition factors

FRAPCON

- FRAPCON simulates fuel thermo-physical behavior over exposure and is used to calculate initial gas gap properties and conditions

METHODOLOGY OVERVIEW: TOOLS

MATLAB (CGS)

- Scripting tool used for automatic generation of core inputs for TRACE

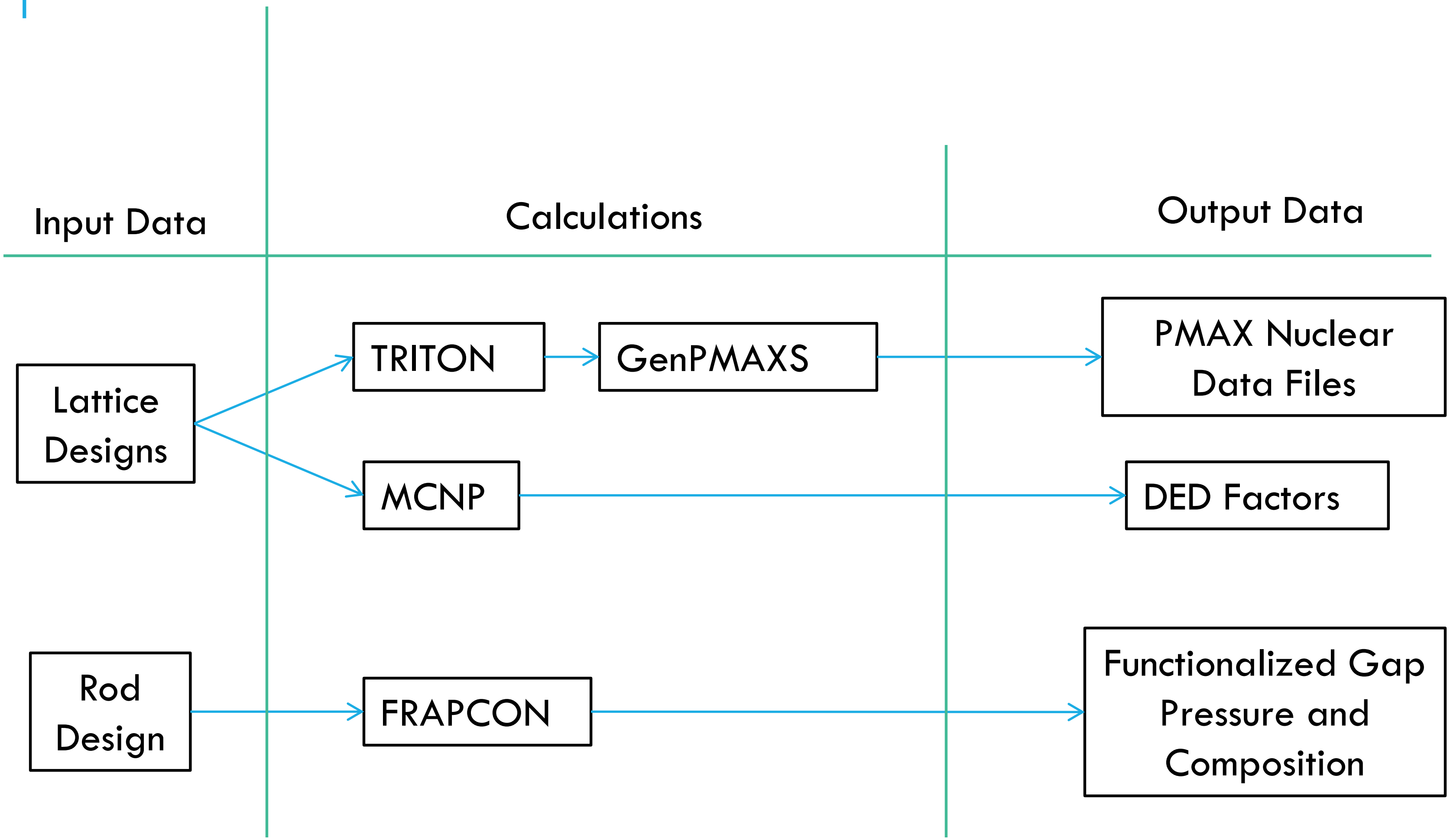
SNAP

- Visualization tool used for generating TRACE thermal-hydraulic, control system, and heat structure models

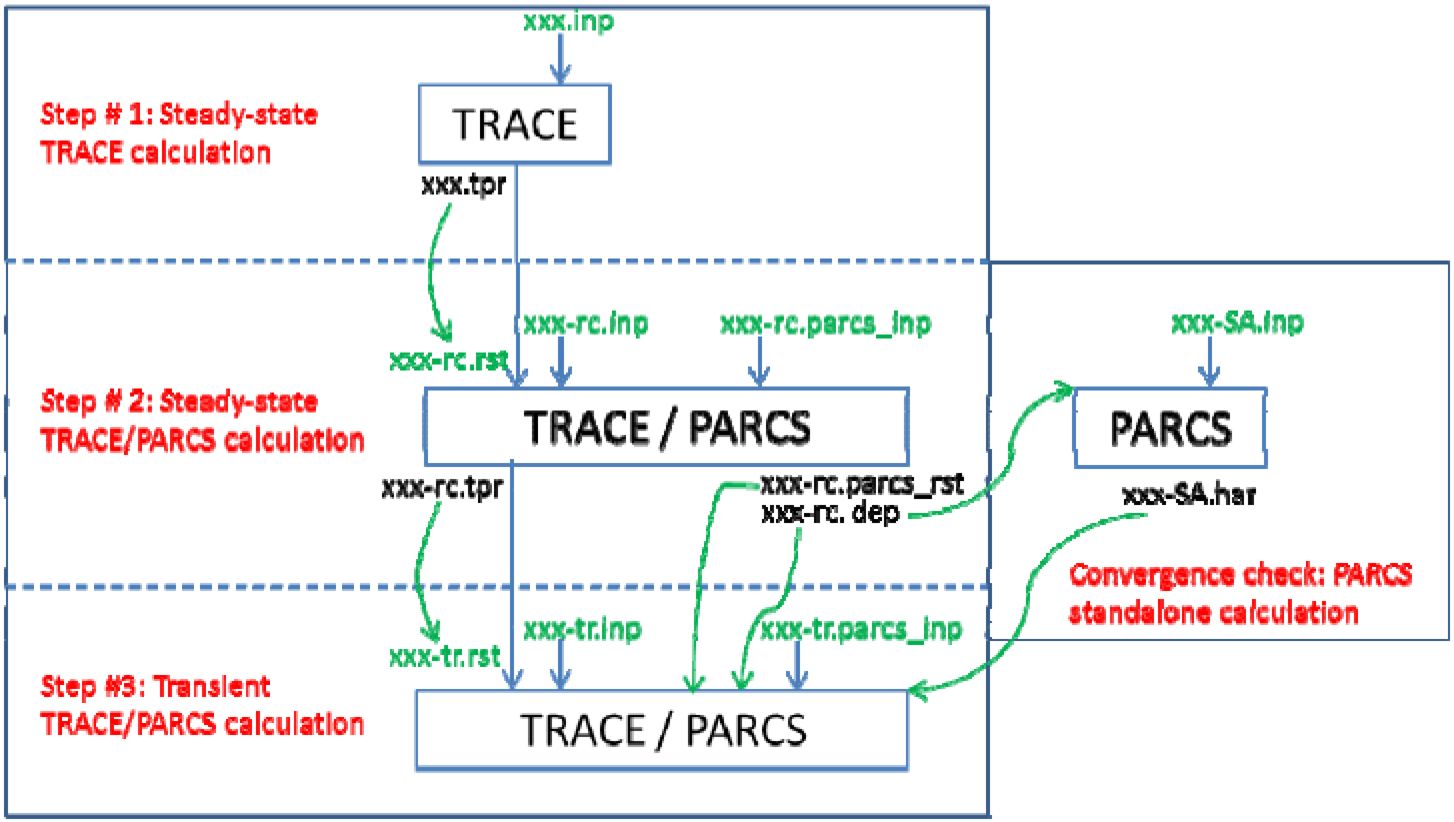
GenPMAXS

- Code that converts TRITON output into PMAX files for use in PARCS

METHODS: FUEL PROPERTIES



METHODS: SYSTEMS ANALYSIS



MELLA+ BENEFITS

The flow control window (FCW) allows

- Global reactivity changes without control blade motion
- Spectral shift operation
- Reduces incidence of Fuel-Clad Interaction (FCI) fuel failure

Reduced control blade pattern swaps

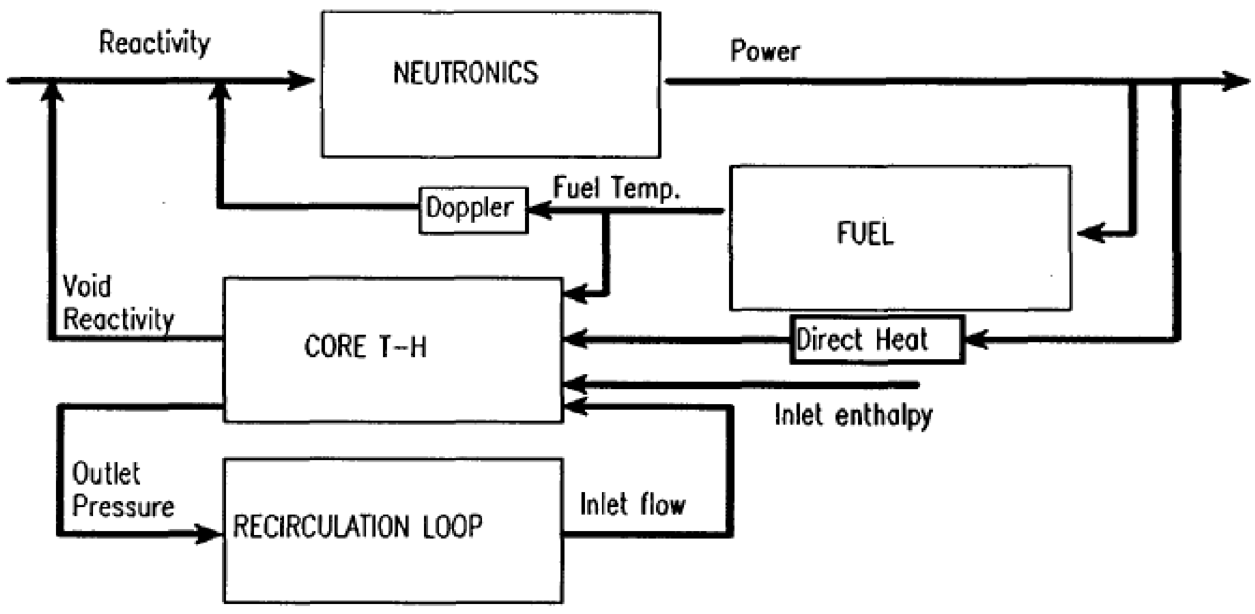
- Reduces incidence of pellet-clad interaction fuel failure

Low-flow depletion (spectral shift)

- Improves fuel cycle economics

SAFETY SIGNIFICANCE

Higher thermal power following 2RPT greatly increases the chances that the reactor will undergo unstable power oscillations. ATWS leading to instability is ATWS-I



EXPERIMENTAL WORK

Experimental study of fuel heat-up mechanisms during power/flow oscillatory conditions typical of ATWS-I scenarios.

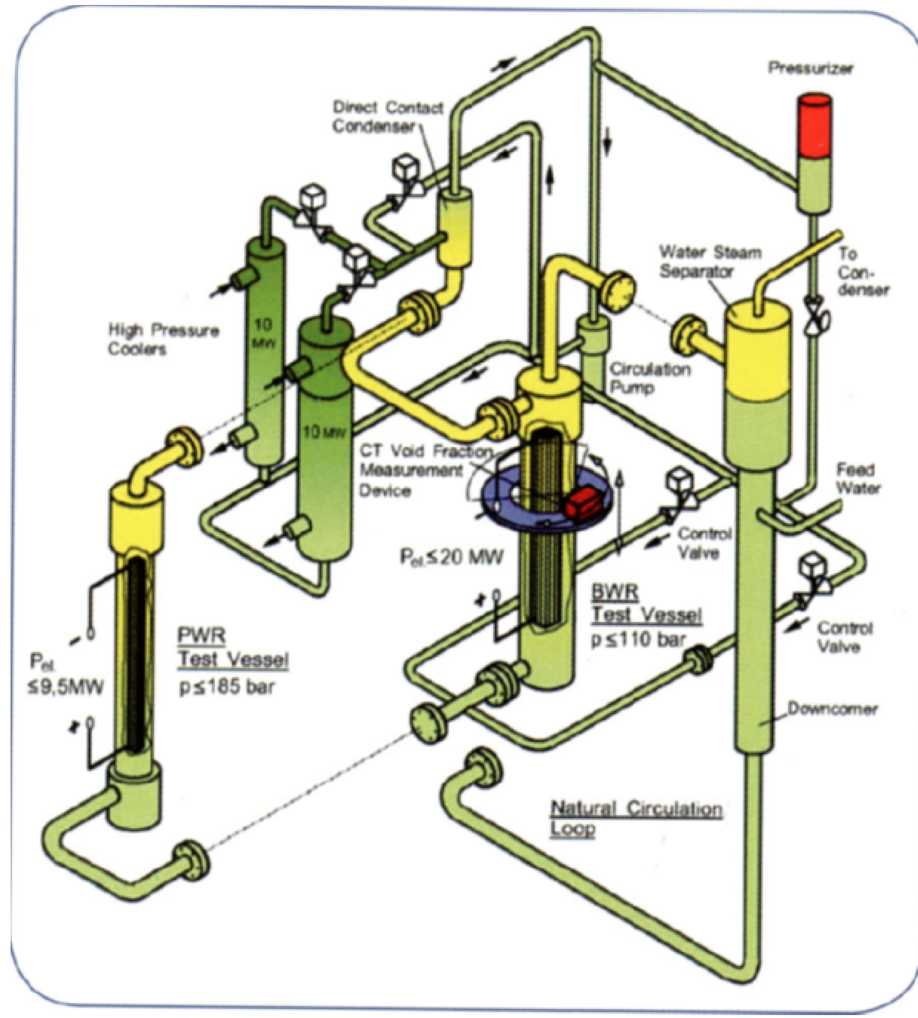
Assessment and validation of TRACE to analyze fuel heat-up during ATWS-I.

Performed extensive testing of failure to rewet conditions at the KATHY test loop in December 2016.

Detailed analysis of the results is still on-going.

KATHY FACILITY

- Full scale bundle test facility
- Full reactor pressure
- Capability for natural circulation flow rate to perform stability and instability tests
- Instrumented to measure temperature for CHF tests, adequate for indicating the failure to rewet phenomenon
- Implements a module called “SINAN” that is unique.
- Heater rods are made of stainless steel, not zircaloy.



U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

BSEP MELLLA+ ATWS-I METHODOLOGY

Dr. Peter Yarsky
US NRC Office of Nuclear Regulatory Research

STEADY-STATE PARCS/PATHS CYCLE ANALYSIS

1. First, cross-sections were generated. The RES staff used CASMO-5 to generate the nuclear data for the reference fuel designs and processed the CASMO-5 output through GenPMAXS to generate PMAX libraries for use in PARCS.
2. Second, a PARCS/PATHS model was developed for the BSEP core using thermal-hydraulic and nuclear design information describing the reference core.
3. Third, an equilibrium cycle search was performed using PARCS/PATHS to reach and then simulate the equilibrium cycle for the reference core design.

PARCS/PATHS STEADY-STATE CALCULATIONS TO SUPPORT TRANSIENT ANALYSIS

1. PARCS/PATHS was used to determine the limiting point in cycle for further analysis, which was established to be the beginning of the equilibrium cycle (BOEC)
2. The steady-state power distribution was calculated for BOEC using PARCS/PATHS. This power distribution is used to determine the channel grouping in subsequent TRACE calculations according to a methodology for channel grouping developed by ORNL with some minor tweaks.
3. PARCS/PATHS was used to calculate the first harmonic shape, this result is used to determine candidate hot channels in the core, but also to provide a HAR file for the use of white noise in the transient calculation.

TRACE CORE MODEL AND FUEL THERMAL-MECHANICAL CONSIDERATION

- The RES staff thermal-mechanical (T-M) modeling capability has advanced since previous MELLLA+ analyses were performed using TRACE. As a consequence, tools that were used to map detailed T-M data from upstream codes to the TRACE core model could not be used without significant modification.
- To support the current licensing schedule, RES staff utilized legacy models in TRACE, which allowed the staff to use legacy mapping tools, but this means that the fuel T-M modeling is rather crude. To account for this in the analysis, each case was run over a significant range of gap conductance (HGAP) values to evaluate the sensitivity to this modeling practice.
- HGAP is varied between 3 and 30 kW/m^2-K in 3 kW/m^2-K increments. Peak cladding temperature (PCT) results are reported for the worst case from this range.

TRACE/PARCS STEADY-STATE INITIALIZATION

1. TRACE is run in a stand-alone mode to converge important core boundary conditions, such as flow, core inlet temperature, flow, and dome pressure. This is done with a modest number of fuel channel components (CHANs) based on the grouping. In this case 42 CHANs are required.
2. TRACE/PARCS is run in coupled mode in steady-state. In addition, numerical solution options are adjusted to match those for use in the transient calculation. The Lax-Wendroff method is used, which uses second order spatial and time differencing with a flux limiter. This method address issues of numerical diffusion.
3. TRACE/PARCS coupled power distributions are compared to PARCS/PATHS power distributions to confirm adequacy of the channel grouping.
4. A null transient is run for 5 seconds to establish that the steady-state solution is adequately converged.

TRANSIENT CALCULATIONS

1. TRACE/PARCS transient calculations restart from the coupled steady-state results.
2. In addition to the 5 second null transient, an additional 5 seconds is run with no transient disturbance other than the activation of the white-noise feature. The white-noise is activated to ensure consistent prediction of instability and is used according to prescribed guidance for the fundamental/core-wide (CW) and first harmonic/out-of-phase (OOP) modes.
3. Various trips and control systems are employed to account for the initiating event (turbine trip), automatic features such as dual recirculation pump trip (2RPT) and turbine bypass valve (TBV), and manual operator actions to lower level and inject boron.
4. Just for the purposes of the RES staff confirmatory analysis, fuel damage is considered to occur if the PCT exceeds 2200 °F.

CHANNEL GROUPING BASED ON BUNDLE POWER

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2										0.297	0.361	0.428	0.468	0.495
3									0.413	0.537	0.622	0.806	0.840	0.856
4						0.348	0.459	0.583	0.684	0.859	0.928	0.985	1.012	1.021
5					0.393	0.697	0.825	0.918	0.984	1.051	1.077	1.102	1.118	1.090
6				0.352	0.699	0.772	0.983	1.074	1.125	1.065	1.075	1.175	1.155	0.950
7				0.487	0.829	0.984	1.085	1.147	1.209	1.108	1.129	1.216	1.212	0.998
8				0.587	0.920	1.075	1.146	1.225	1.233	1.248	1.238	1.278	1.264	1.248
9			0.417	0.686	0.986	1.125	1.208	1.233	1.259	1.242	1.247	1.279	1.304	1.281
10		0.300	0.541	0.862	1.052	1.064	1.106	1.248	1.248	0.931	0.997	1.268	1.280	1.191
11		0.364	0.641	0.931	1.078	1.074	1.128	1.237	1.248	0.997	0.993	1.278	1.316	1.197
12		0.427	0.808	0.986	1.102	1.174	1.213	1.278	1.282	1.270	1.280	1.324	1.333	1.325
13		0.467	0.839	1.012	1.117	1.152	1.211	1.267	1.305	1.289	1.316	1.329	1.330	1.308
14		0.494	0.854	1.020	1.087	0.947	0.991	1.247	1.279	1.190	1.192	1.322	1.301	0.933

CHECKING CHANNEL GROUPING

Bundle Power RMS Difference is ~ 7 percent

	2	3	4	5	6	7	8	9	10	11	12	13	14
2									0.08	0.08	0.07	0.07	0.06
3								0.07	0.12	0.12	0.10	0.08	0.08
4					0.08	0.07	0.08	0.10	0.08	0.07	0.04	0.03	0.03
5				0.08	0.11	0.08	0.06	0.04	0.04	0.02	0.01	-0.01	0.01
6			0.08	0.11	0.08	0.02	-0.01	0.00	0.05	0.06	-0.02	-0.02	0.05
7			0.07	0.07	0.02	-0.04	-0.06	-0.04	0.03	0.02	-0.03	-0.04	0.05
8			0.08	0.06	-0.02	-0.06	-0.08	-0.08	-0.06	-0.05	-0.08	-0.07	-0.06
9		0.07	0.10	0.04	0.00	-0.05	-0.08	-0.08	-0.06	-0.07	-0.10	-0.09	-0.08
10	0.08	0.12	0.08	0.04	0.05	0.03	-0.06	-0.06	0.02	0.00	-0.10	-0.09	-0.03
11	0.07	0.11	0.06	0.01	0.05	0.02	-0.06	-0.08	0.00	-0.02	-0.11	-0.11	-0.04
12	0.07	0.09	0.03	0.00	-0.04	-0.04	-0.09	-0.10	-0.10	-0.11	-0.13	-0.13	-0.12
13	0.06	0.07	0.02	-0.02	-0.03	-0.05	-0.08	-0.10	-0.11	-0.11	-0.13	-0.14	-0.11
14	0.06	0.07	0.02	0.00	0.04	0.02	-0.07	-0.09	-0.04	-0.04	-0.12	-0.11	-0.01

HGAP VS. BURNUP FOR 10X10 FUEL FOR 7 KW/FT INITIAL PEAK LINEAR GENERATION RATE

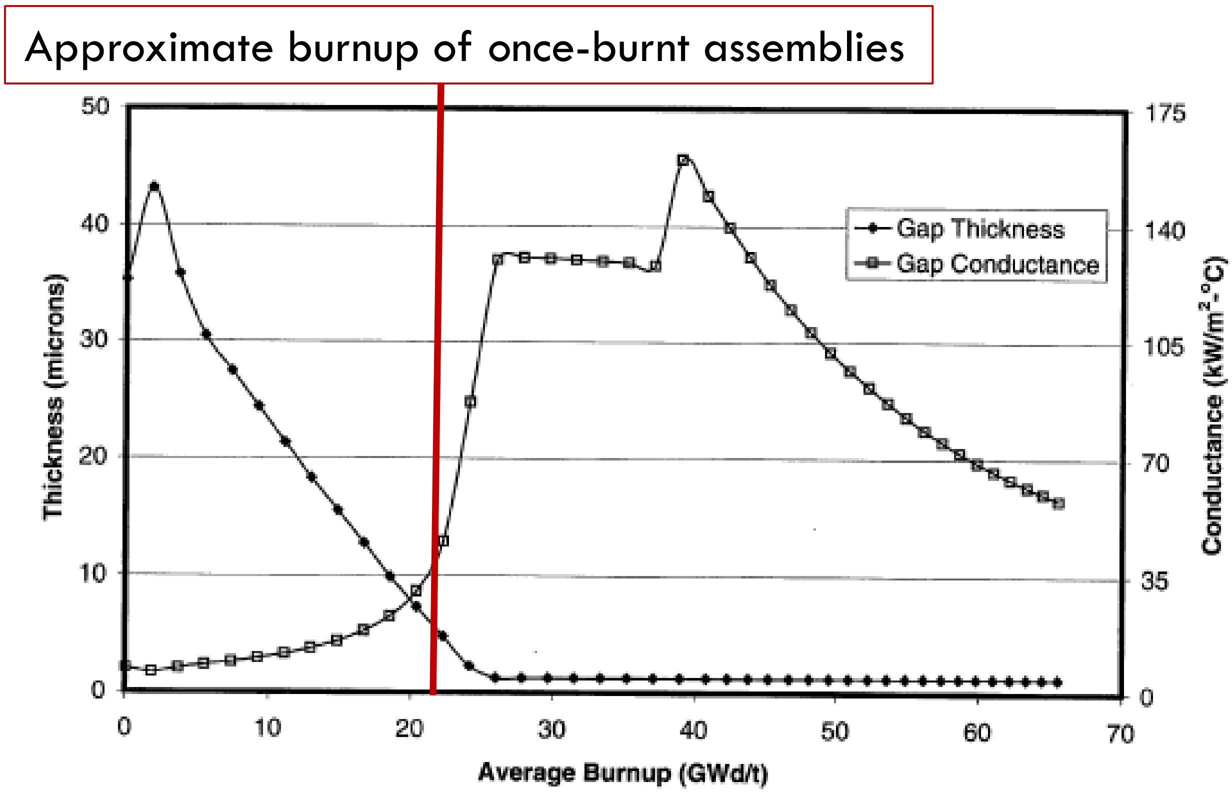
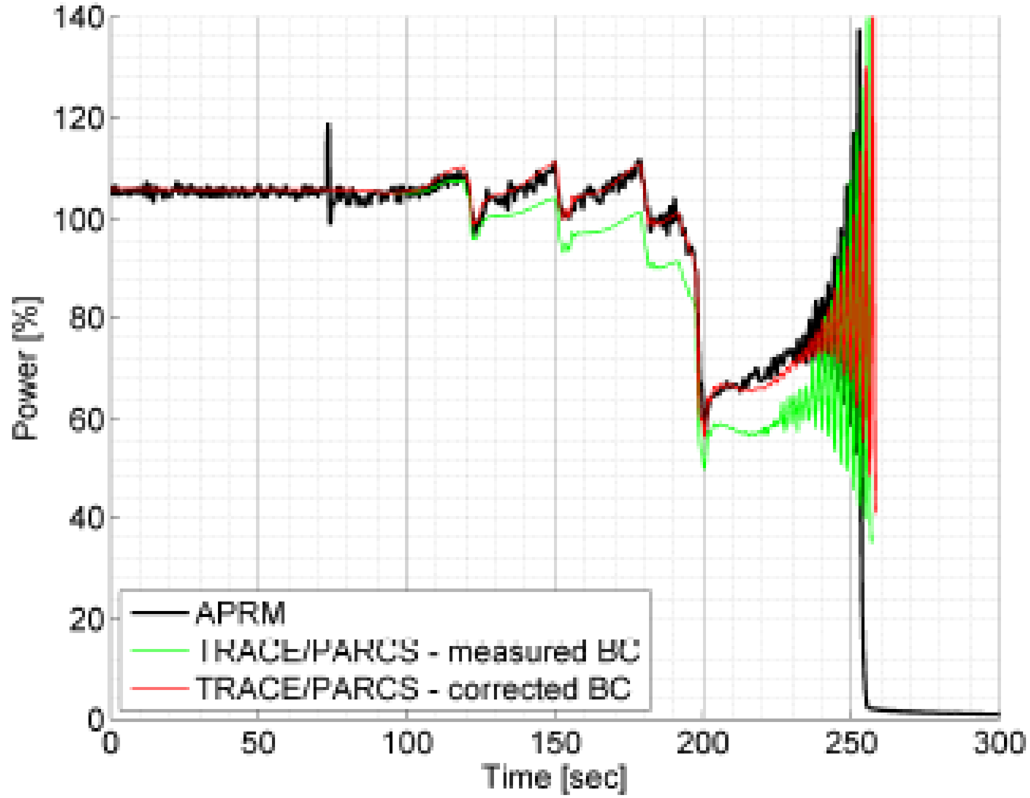
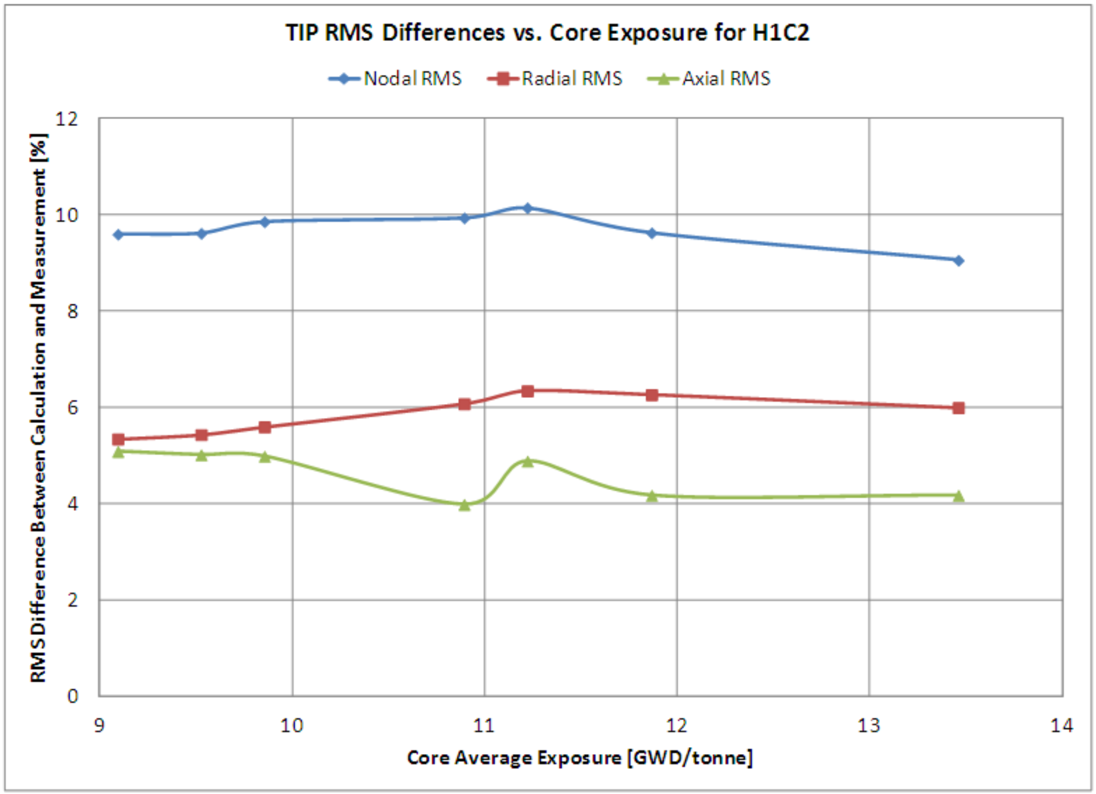


Fig. 7-9. Gap thickness and gap conductance for a BWR 10x10 fuel rod with initial peak power of 7 kW/ft.

VALIDATION: OECD OSKARSHAMN-2 BENCHMARK



VALIDATION: HATCH UNIT 1 C1-C3



The mean bias in k-eff was -873 pcm with a standard deviation of 332 pcm.

The estimated calculation uncertainties were approximately 8 percent for nodal, 4.5 percent for radial, and 5 percent for axial.

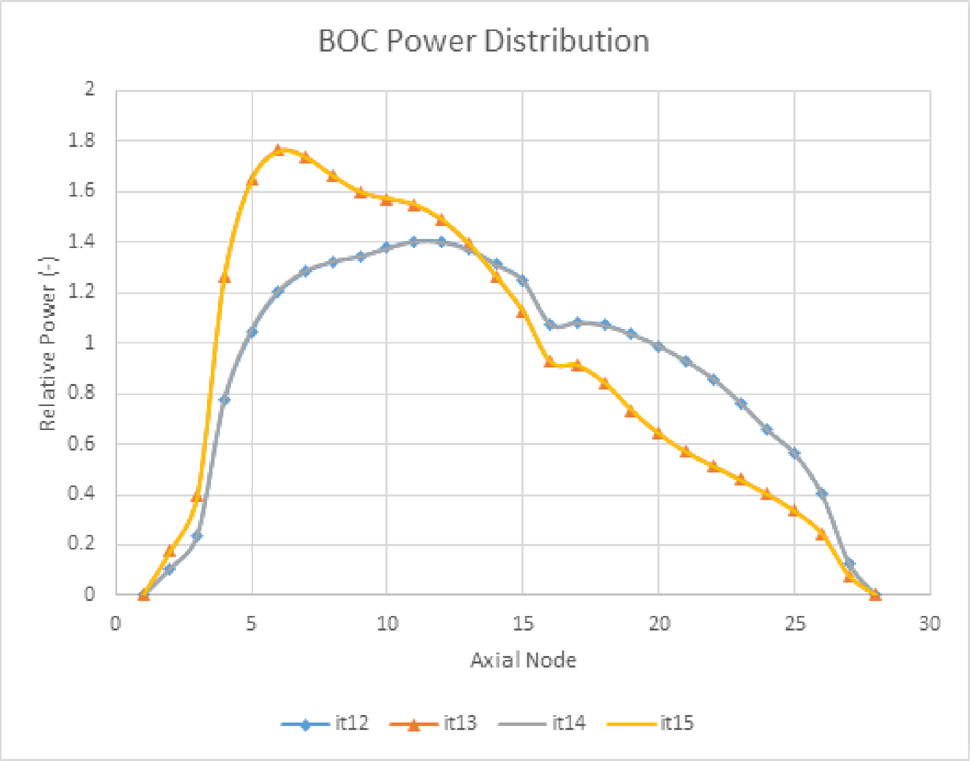
PARCS/PATHS agreement with data indicates all relevant trends are predicted reasonably.

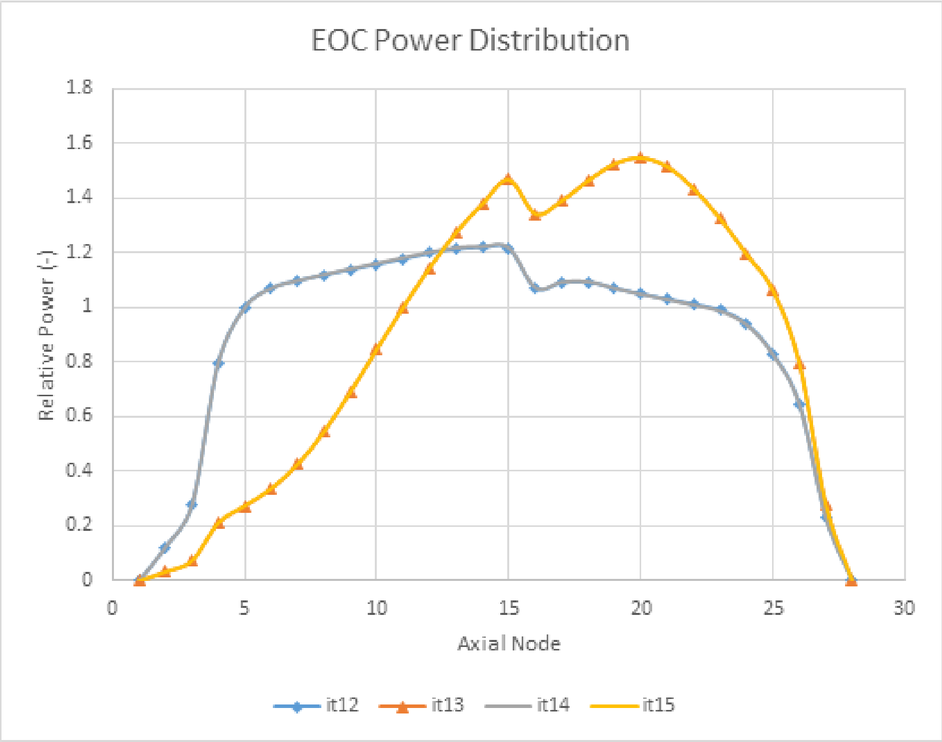
NOVEL APPROACH FOR EQUILIBRIUM CYCLE SEARCH FOR BI-MODAL CYCLE SOLUTION

Initial equilibrium cycle searches did not yield a true equilibrium cycle. Rather, the equilibrium cycle search converged to a 2-cycle solution where the nth cycle was different from the n+1th cycle, but the n+2th cycle was equivalent to the nth cycle.

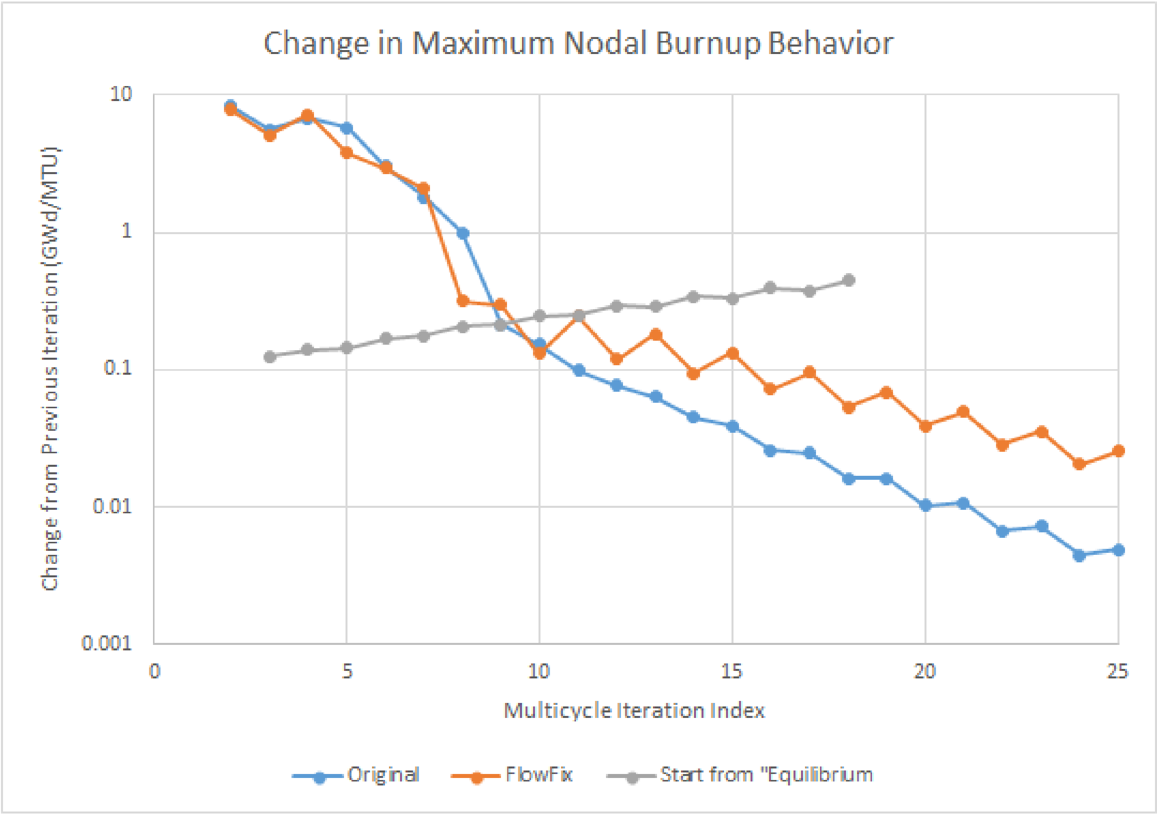
This situation can be avoided using a novel approach developed by the staff where the initial burnup arrays at the start of each cycle in the search are computed based on the average of the end-of-cycle arrays based on all cycles up until cycle n. This potentially slows down the equilibrium cycle search convergence, but ensures that a single cycle is identified as the equilibrium cycle.

2-CYCLE SOLUTION: POWER SHAPES

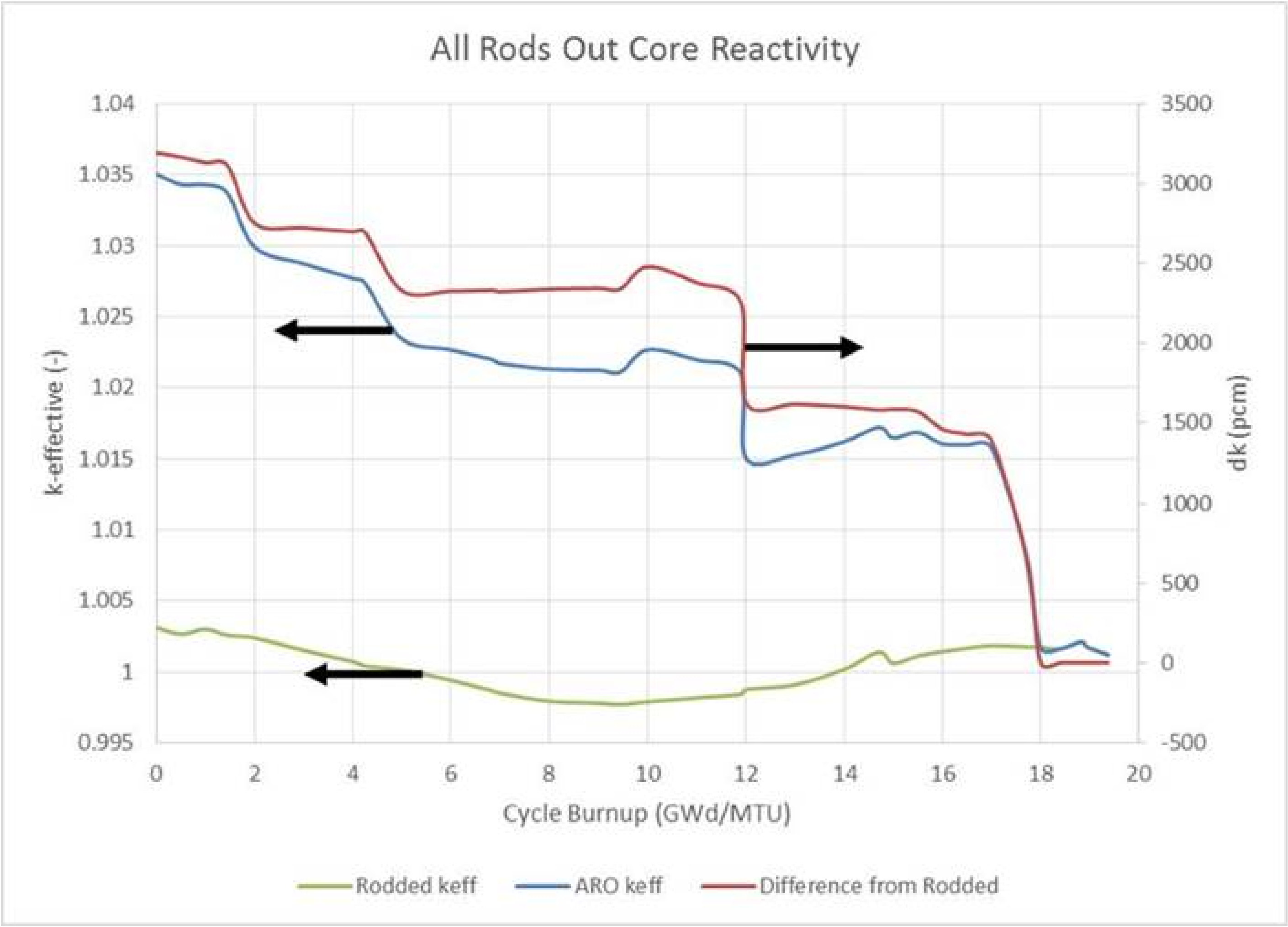




2-CYCLE SOLUTION



BOEC LIMITING



U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

REFERENCE SCENARIO ANALYSIS

Dr. Peter Yarsky
US NRC Office of Nuclear Regulatory Research

SEQUENCE OF EVENTS

10 seconds

- Turbine trips causing fast closure of turbine stop valve
- Dual recirculation pump trip signal on turbine trip
- Extraction steam flow to feedwater heaters is isolated

~11 seconds

- Dome pressure reaches ~8.5 MPa
- Safety-relief valves first open
- Turbine bypass valve opens

~40 seconds

- Core is unstable – out-of-phase mode is more limiting but bi-modal, non-linear oscillations eventually develop

~60 seconds

- Level increases and reaches a steady bias of ~1 m high

SEQUENCE OF EVENTS

~70 seconds

- Significant fuel heat-up occurs

~100-150 seconds

- PCT is reached

125 seconds

- Operators initiate SLCS injection

130 seconds

- Operators terminate feed flow and begin to control level to TAF+90”

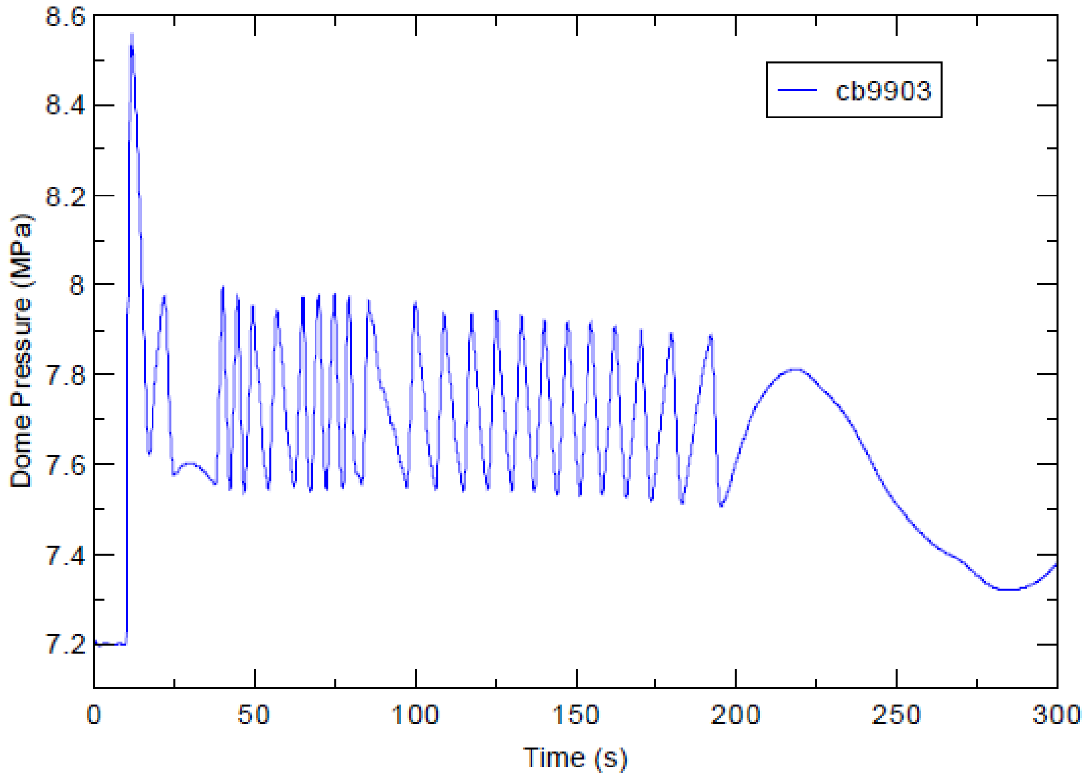
~140 seconds

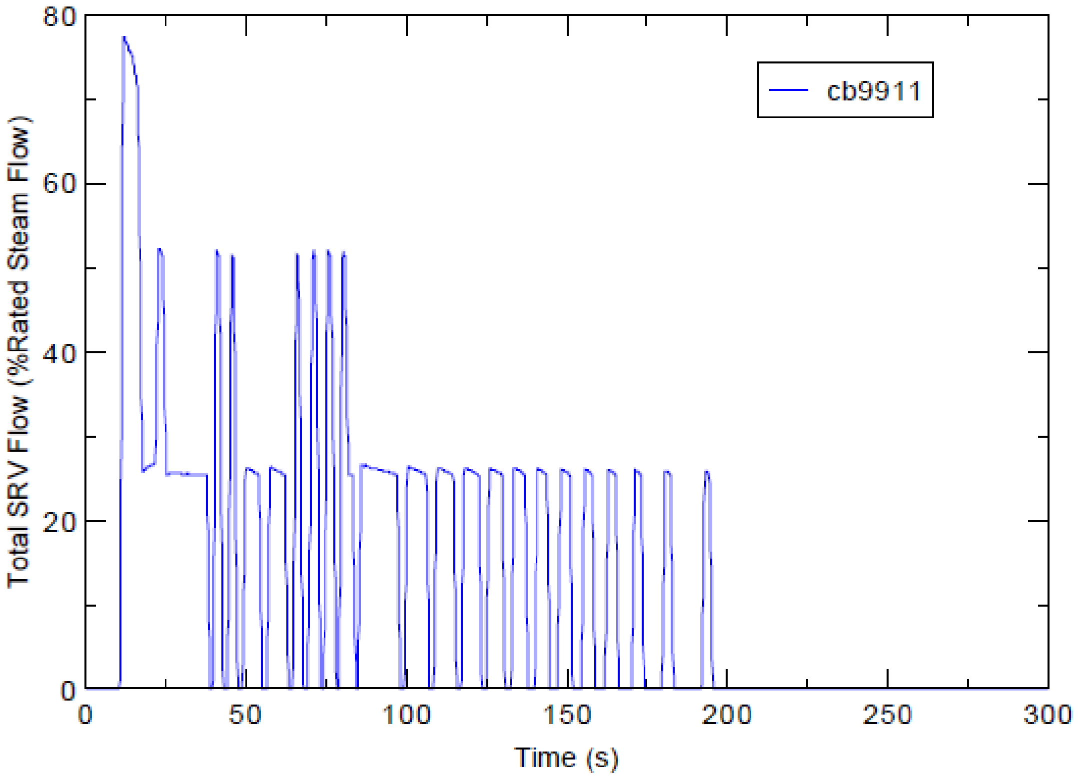
- Core inlet subcooling begins to decrease rapidly

~240 seconds

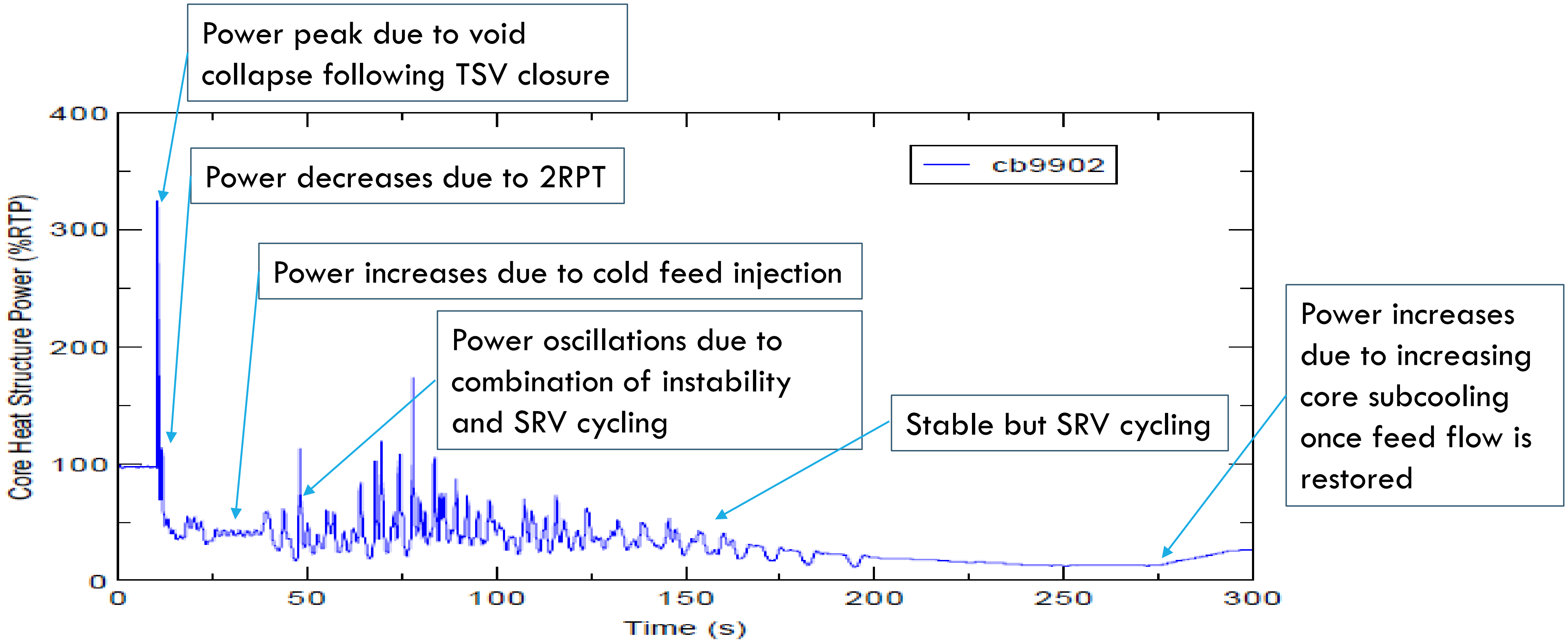
- Operators restore feed flow to maintain level at TAF+90”

DOME PRESSURE AND SRV FLOW

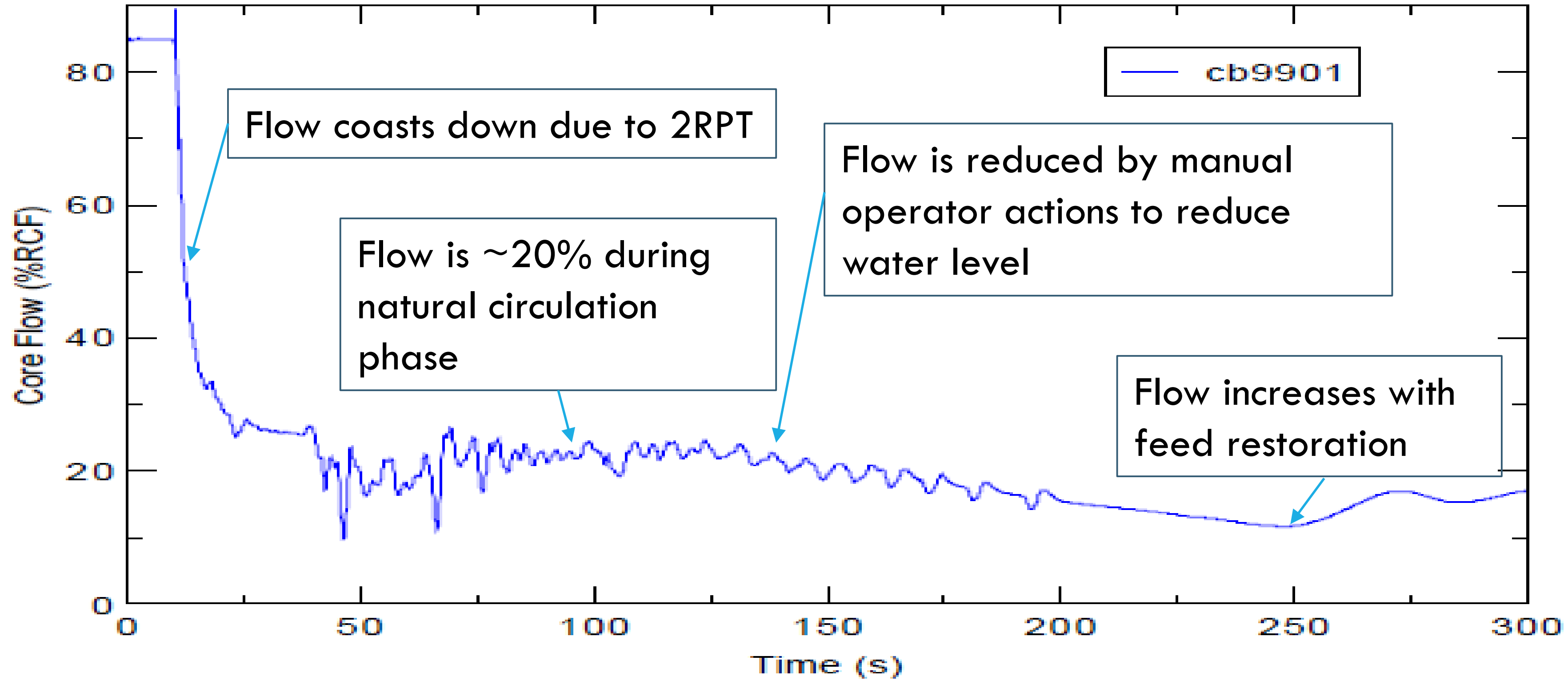




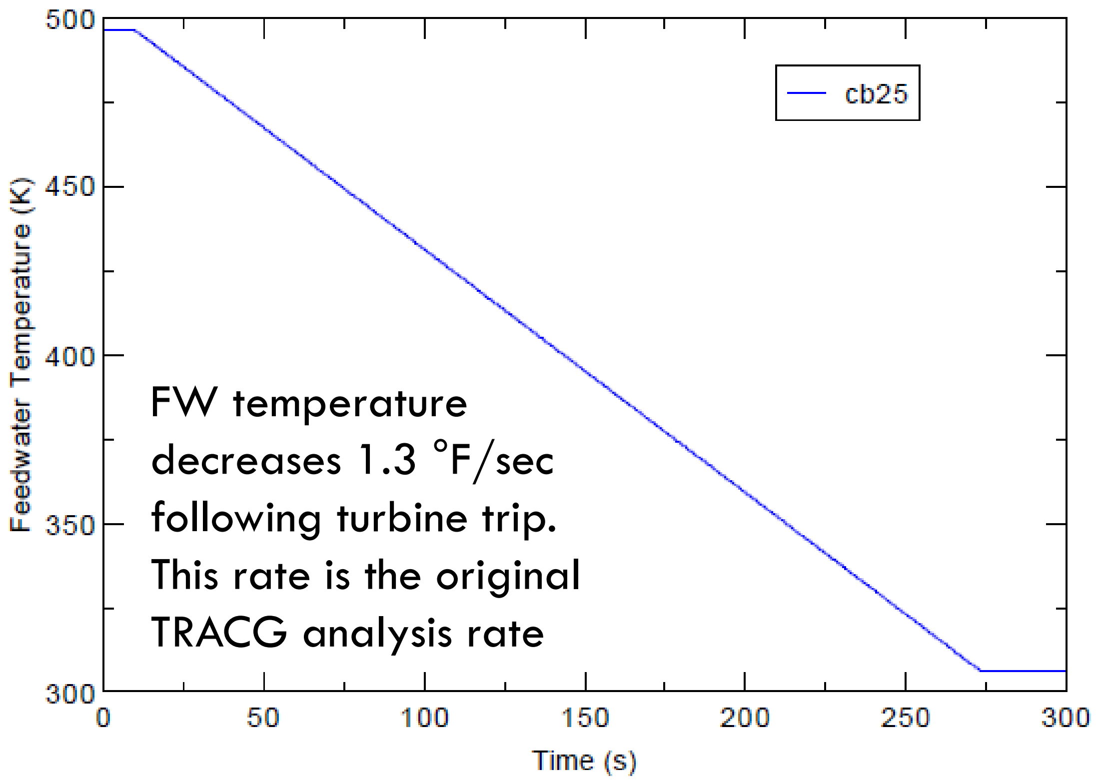
CORE POWER

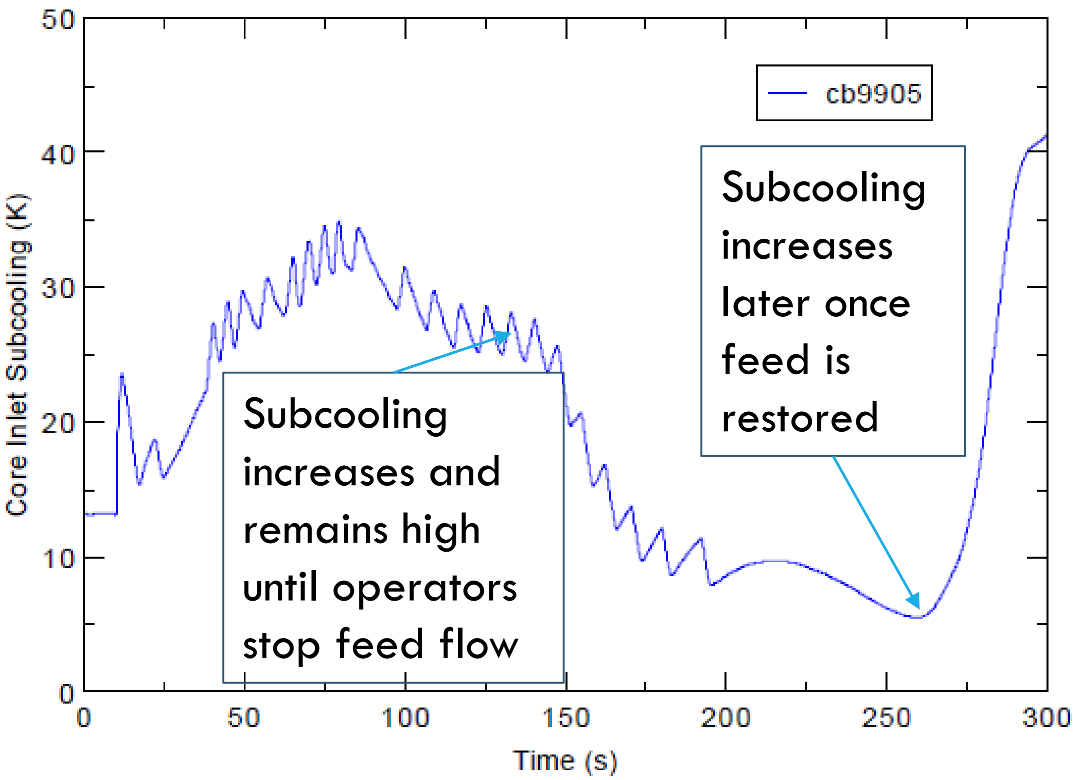

Power peak due to void collapse following TSV closure
Power decreases due to 2RPT
Power increases due to cold feed injection
Power oscillations due to combination of instability and SRV cycling
Stable but SRV cycling
Power increases due to increasing core subcooling once feed flow is restored
cb9902
Core Heat Structure Power (%RTP)
Time (s)
0
100
200
300
400
0
50
100
150
200
250
300

CORE FLOW RATE

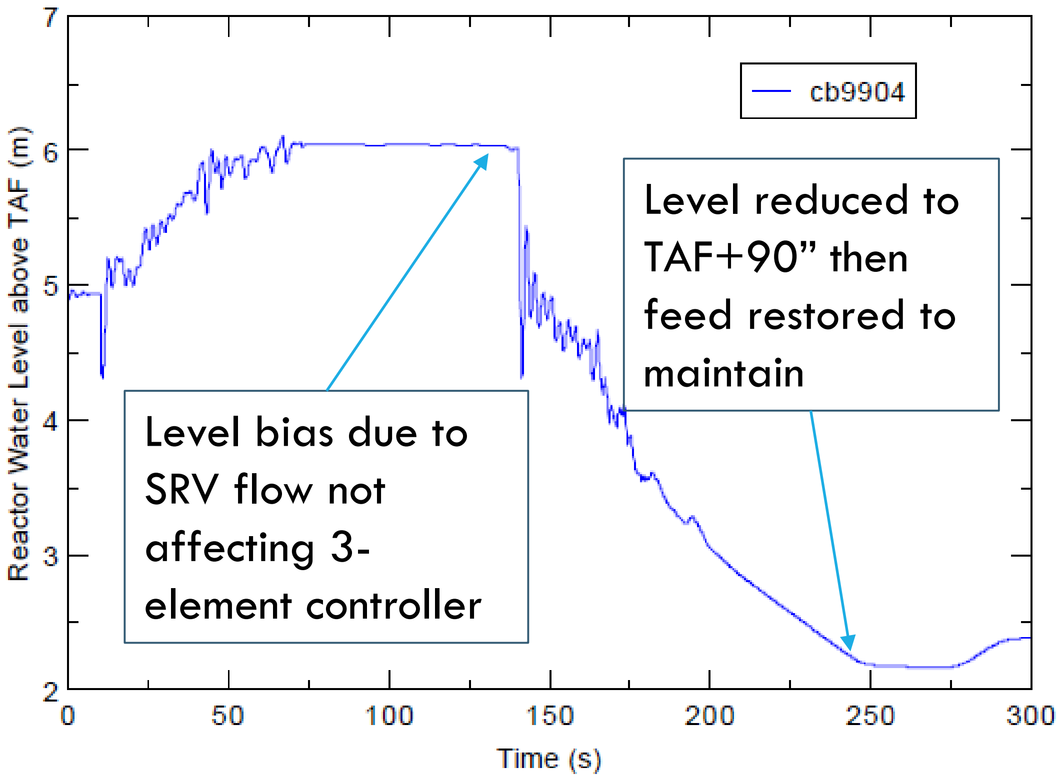


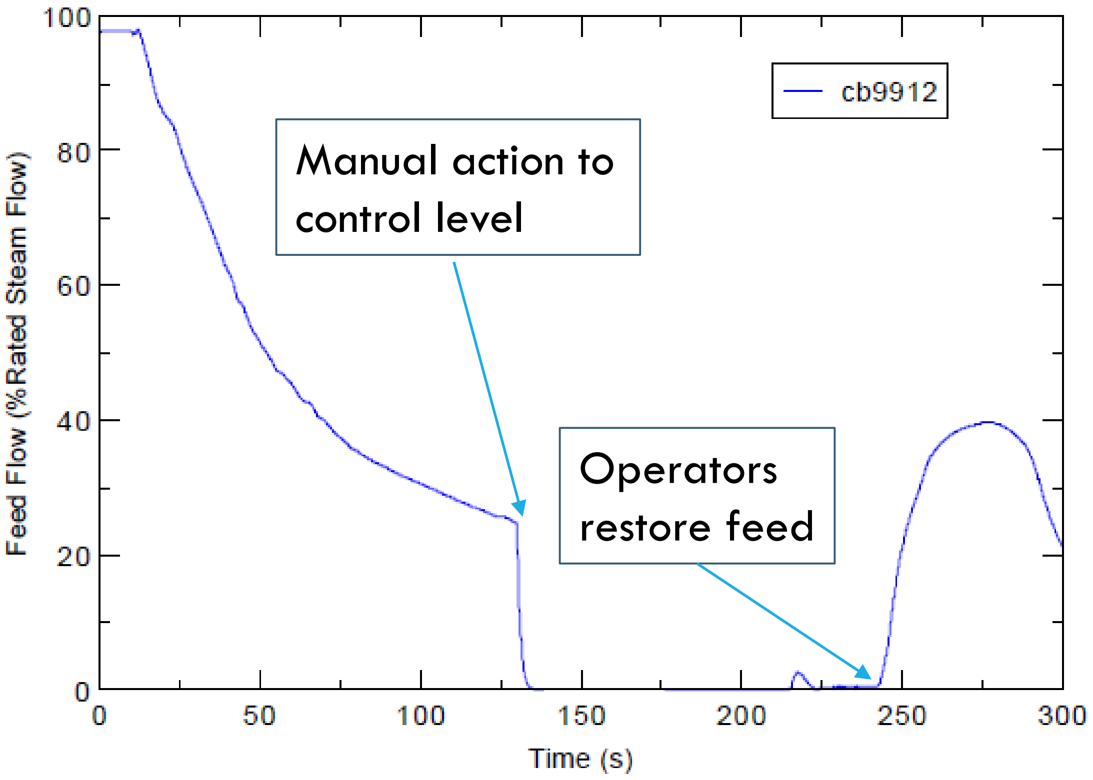
FEED TEMPERATURE AND INLET SUBCOOLING



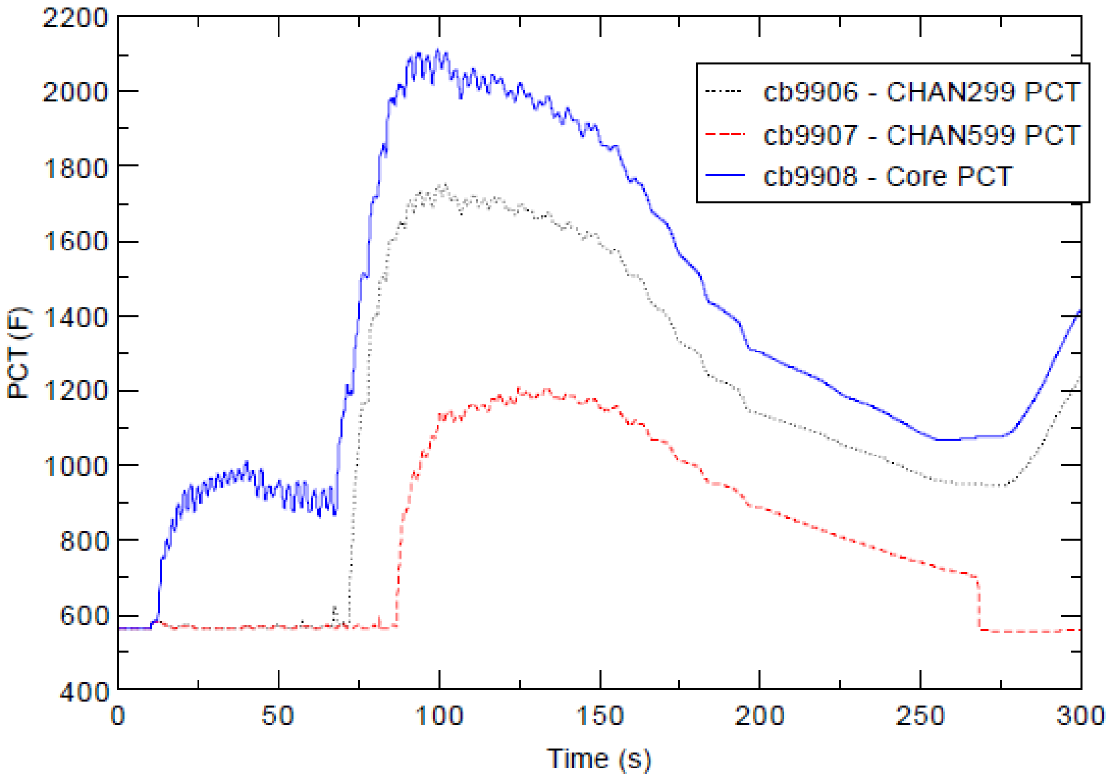


WATER LEVEL AND FEEDWATER FLOW





PEAK CLADDING TEMPERATURE (PCT)



- PCT in average powered rods in candidate hot channels increases following onset of large amplitude power oscillations.
- PCT increases early due to dryout in the initial phase of the transient, likely due to conservatism in TRACE prediction of critical power.
- Core PCT increase significantly once instability starts, reaching maximum of ~2100 °F at ~100 seconds.
- Second peak PCT is ~200-300 °F lower.

SECOND PEAK PCT

During the late transient power increases in response to an increase in inlet subcooling.

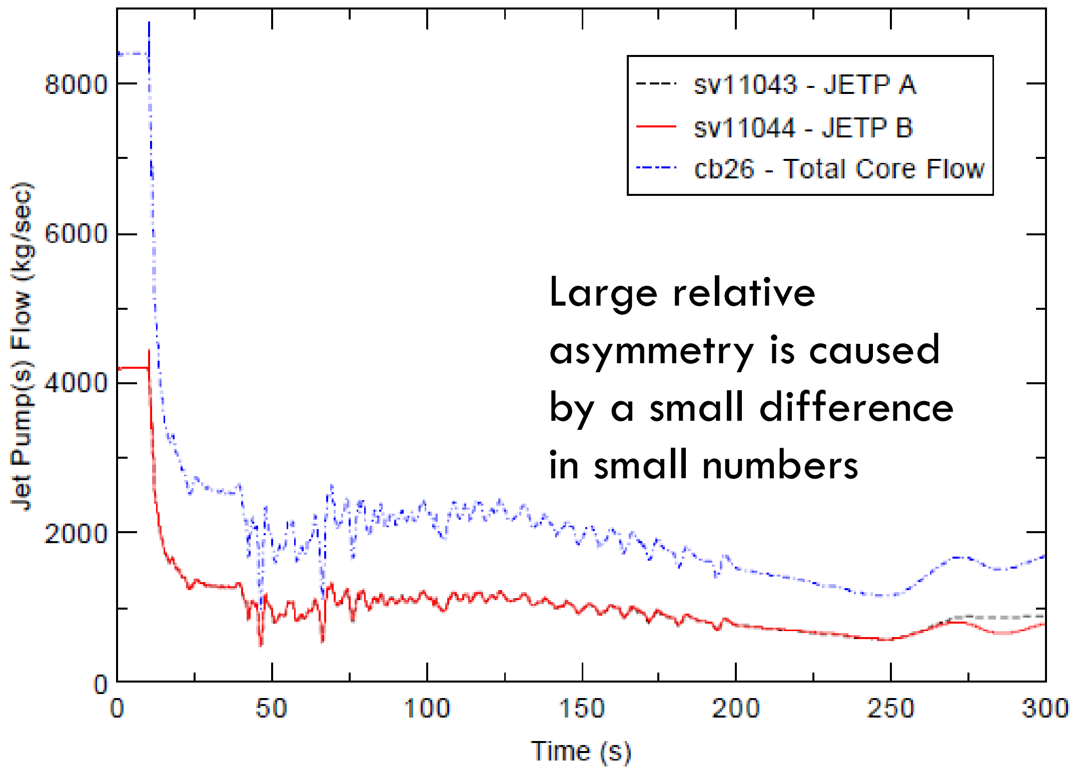
TRACE is likely over-predicting the degree of increased subcooling once feedwater flow is restored due to under-predicting the condensation heat transfer in the steam space above the downcomer liquid level. This is a conservatism in the TRACE calculation.

This leads to a second peak in the PCT late in the transient. However, this second peak in the PCT is always bounded by the earlier peak in the PCT because the accumulation of boron in the core from the SLCS injection suppresses further oscillations and limits the average increase in core power.

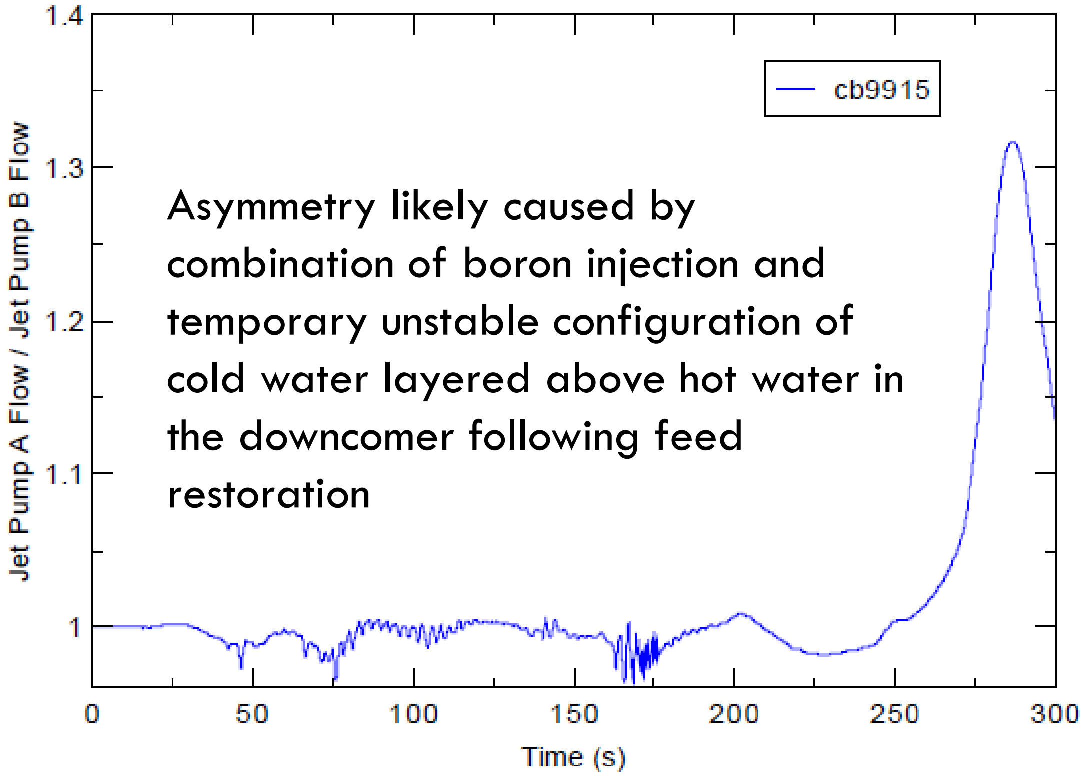
CONCLUSIONS

1. Reference scenario analysis confirms that manual operator actions to inject boron and reduce water level are effective to suppress the instability and to bring the reactor to a downward PCT trajectory.
2. Calculations performed with the worst combination of feedwater temperature rate, operator action timing, and gap conductance produce PCTs below 2200 °F, indicating there is no fuel damage.
3. TRACE may under-predict condensation heat transfer once feed flow is restored and the feedwater injection is into the steam atmosphere above the liquid level in the downcomer. As a result, TRACE predicts an increase in core inlet subcooling that is larger than expected after feed flow is restored to maintain level. However, because the peak PCT has already been achieved, the TRACE calculation results in this phase do not impact conclusions with respect to PCT consequences.

ASYMMETRY

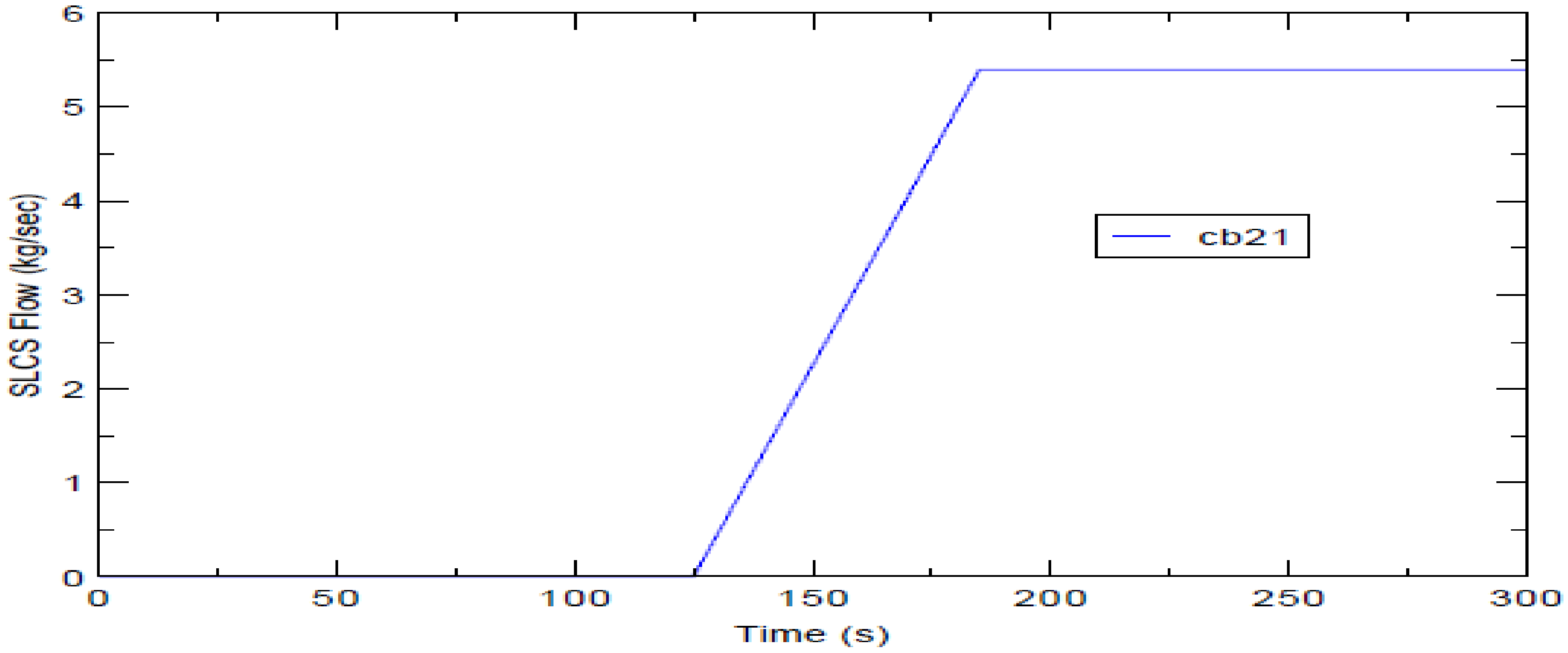


8000
6000
4000
2000
0
0
50
100
150
200
250
300
Time (s)
Jet Pump(s) Flow (kg/sec)
sv11043 - JETP A
sv11044 - JETP B
cb26 - Total Core Flow
Large relative asymmetry is caused by a small difference in small numbers

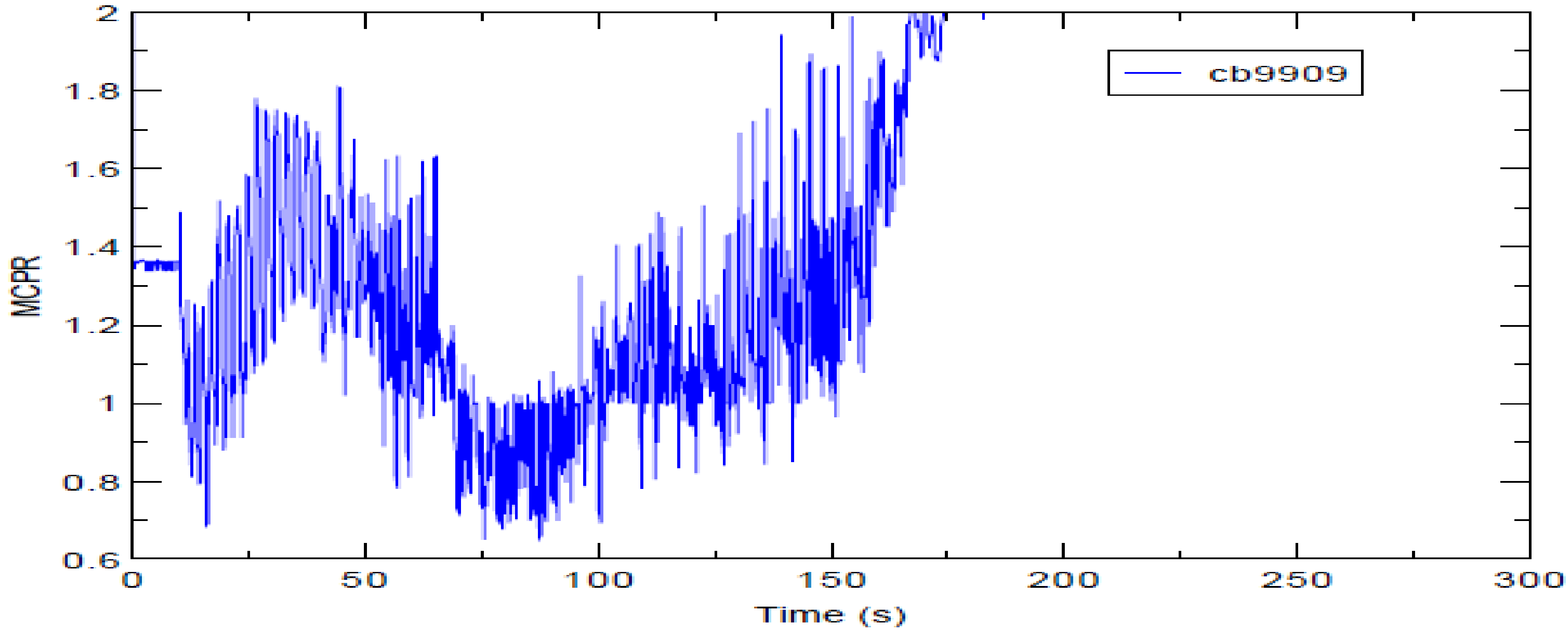


1.4
1.3
1.2
1.1
1
0
50
100
150
200
250
300
Time (s)
Jet Pump A Flow / Jet Pump B Flow
cb9915
Asymmetry likely caused by combination of boron injection and temporary unstable configuration of cold water layered above hot water in the downcomer following feed restoration

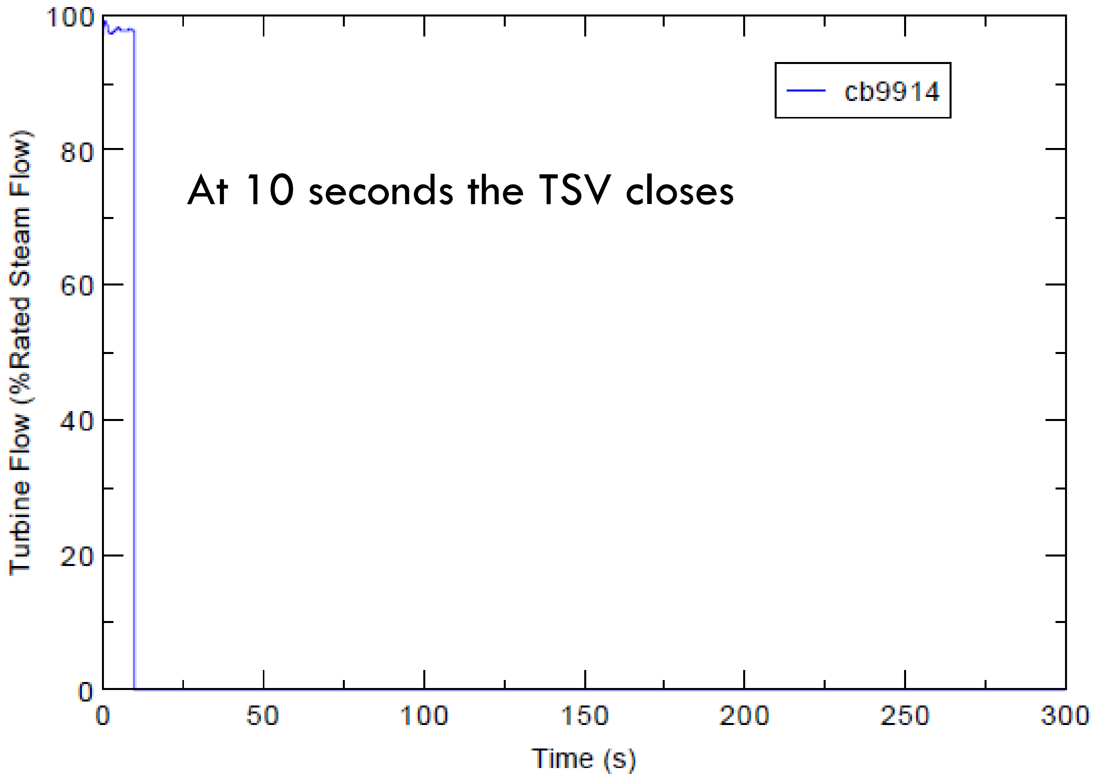
SLCS

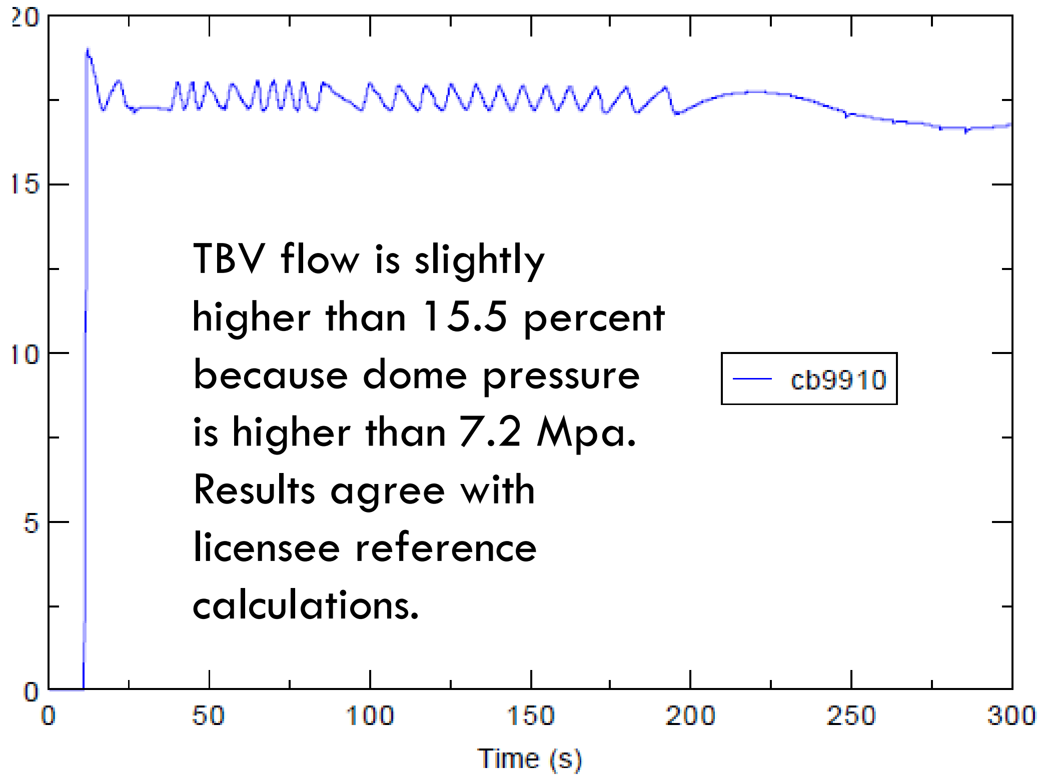


MCPR

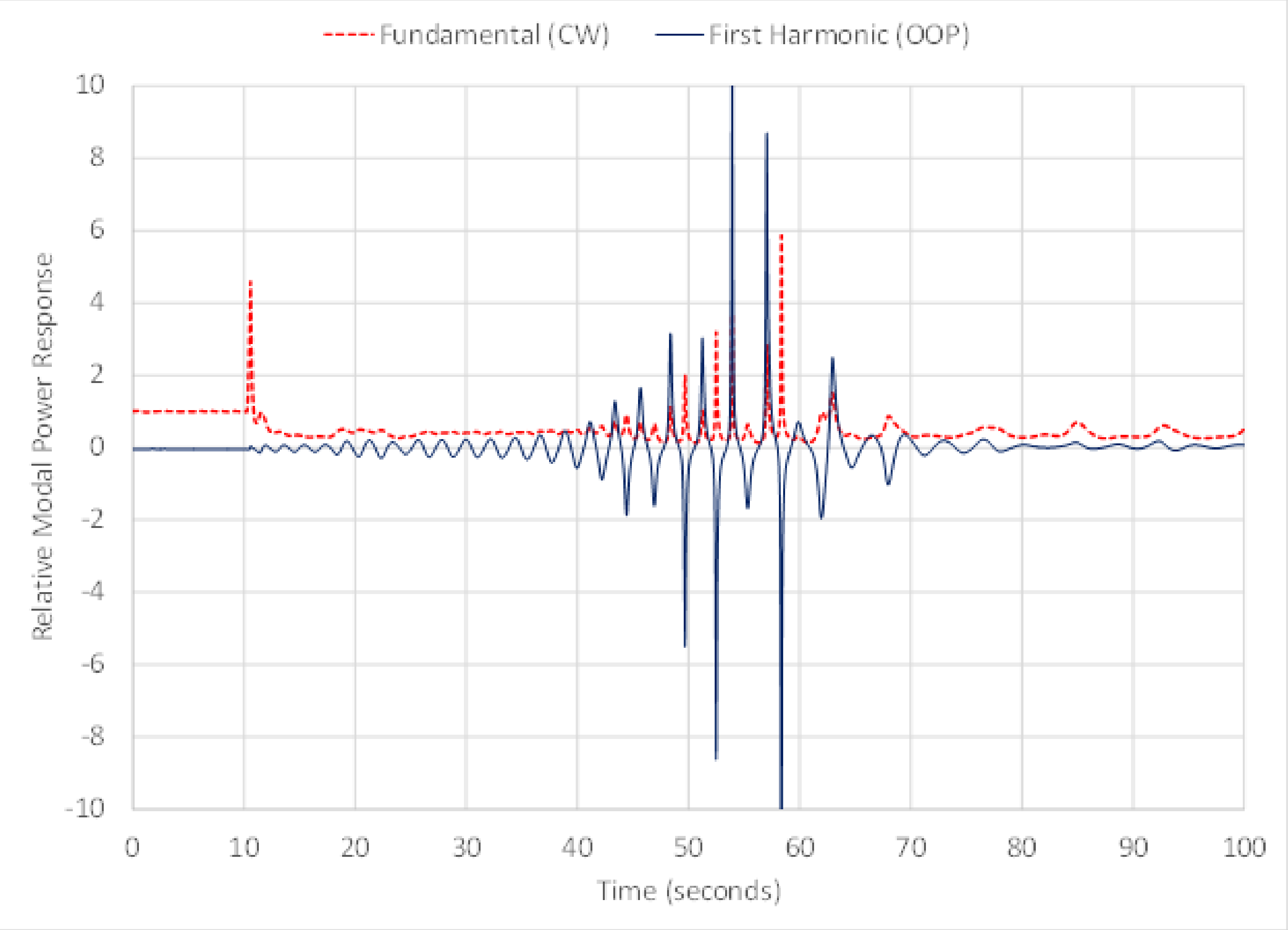


TURBINE AND TBV FLOW

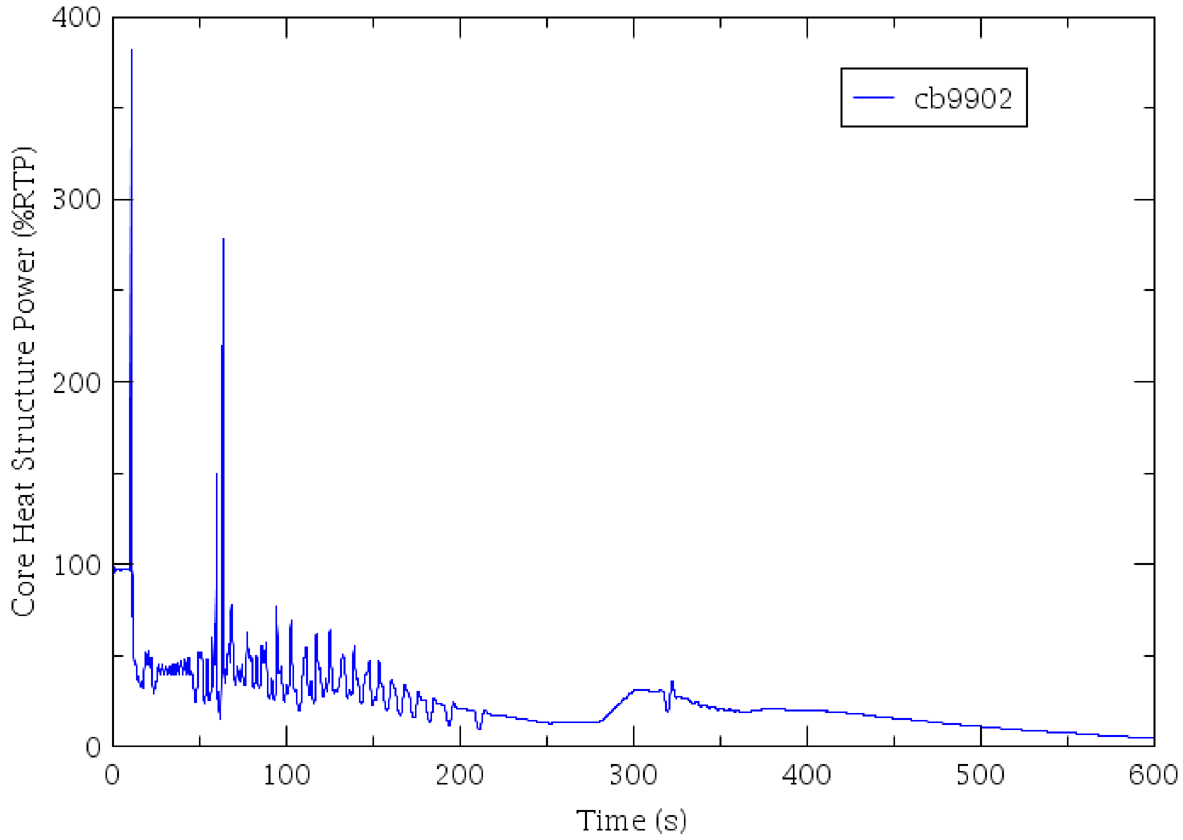




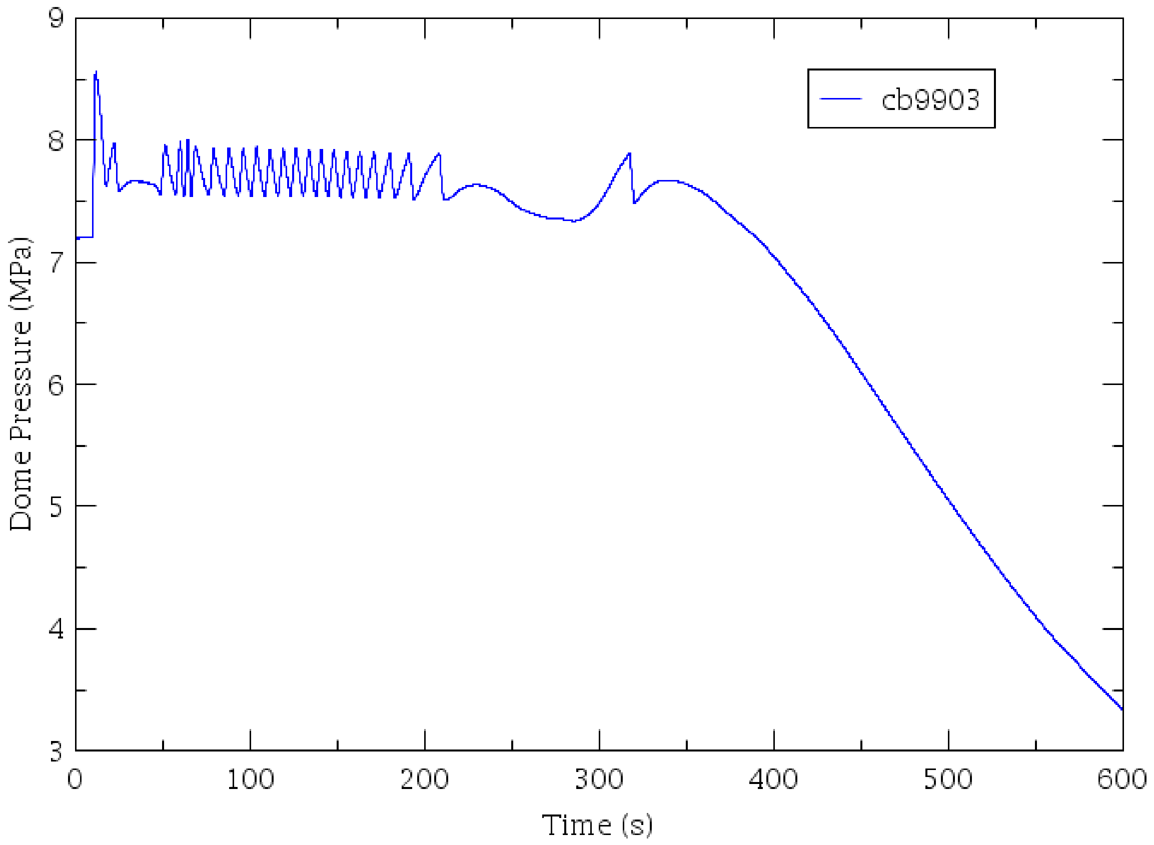
OOP VS. CW MODE



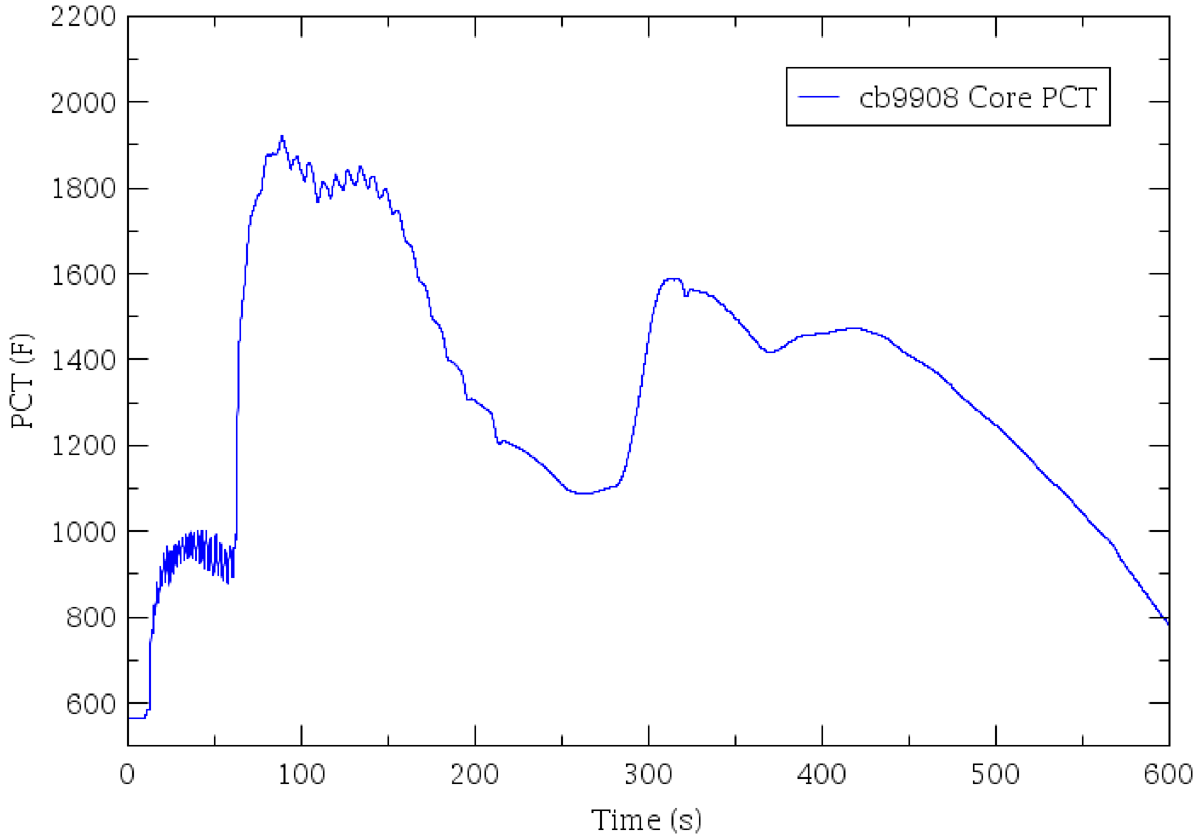
600 SECONDS CORE POWER



600 SECONDS DOME PRESSURE



600 SECONDS PCT



SENSITIVITY STUDIES

Dr. Peter Yarsky
US NRC Office of Nuclear
Regulatory Research

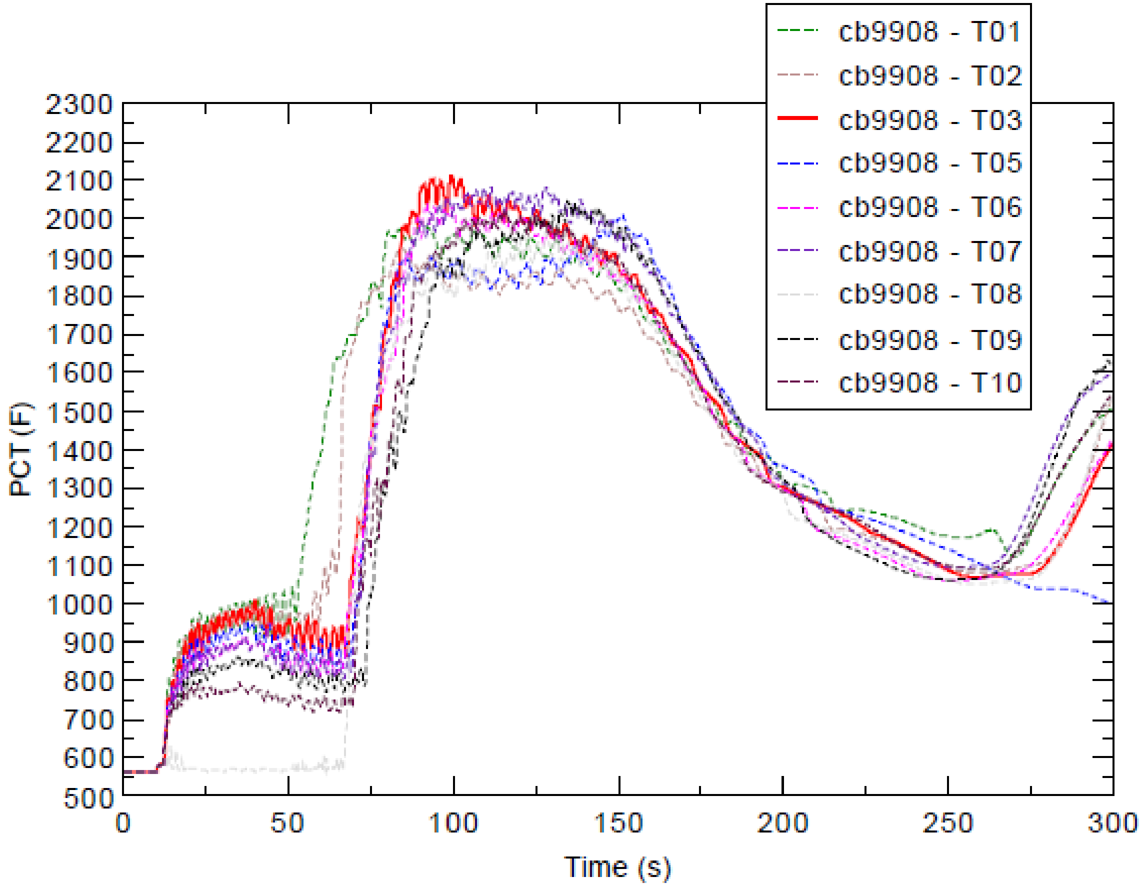
SCOPE OF SENSITIVITY STUDIES

1. Effect of Gap Conductance
2. Effect of Feedwater Temperature Transient
3. Effect of Operator Action Timing

GAP CONDUCTANCE SENSITIVITY

Case	T-Index	HGAP	PCT	Time of peak PCT	Time when PCT > 1200 °F
		kW/m^2-K	°F	sec	sec
2-1	1	3	1914	82	56
2-1	2	6	1822	96	71
2-1	3	9	1745	114	82
2-1	4	12	1988	83	64
2-1	5	15	1787	113	75
2-1	6	18	1867	117	73
2-1	7	21	1840	125	84
2-1	8	24	1844	107	75
2-1	9	27	1573	121	85
2-1	10	30	1549	99	84

PCT TRANSIENT



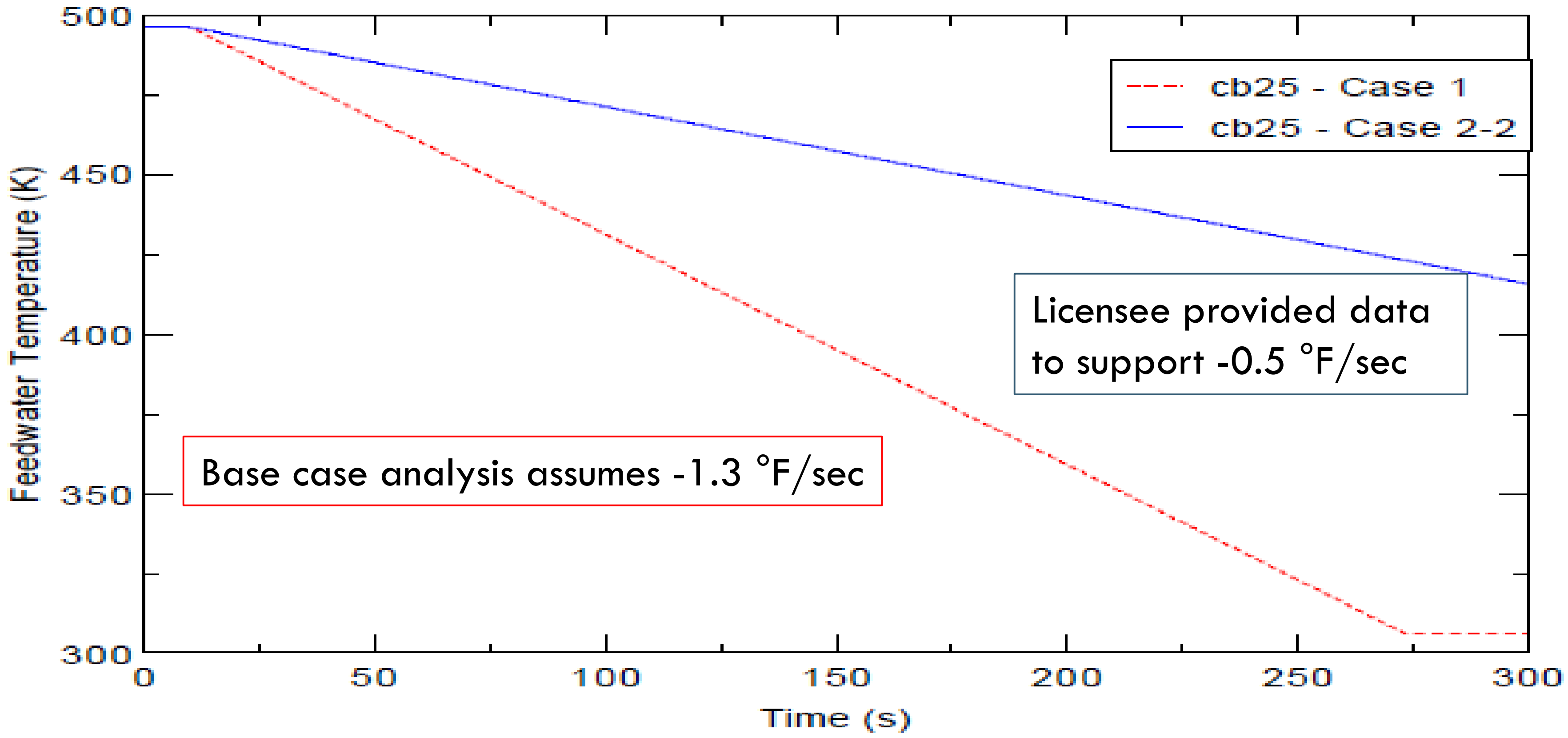
- PCT results are relatively insensitive to HGAP
- PCT ranges from ~1900 to ~2100 °F
- Overall behavior and major trends are consistent all HGAP values analyzed

CASE 2-2 DESCRIPTION

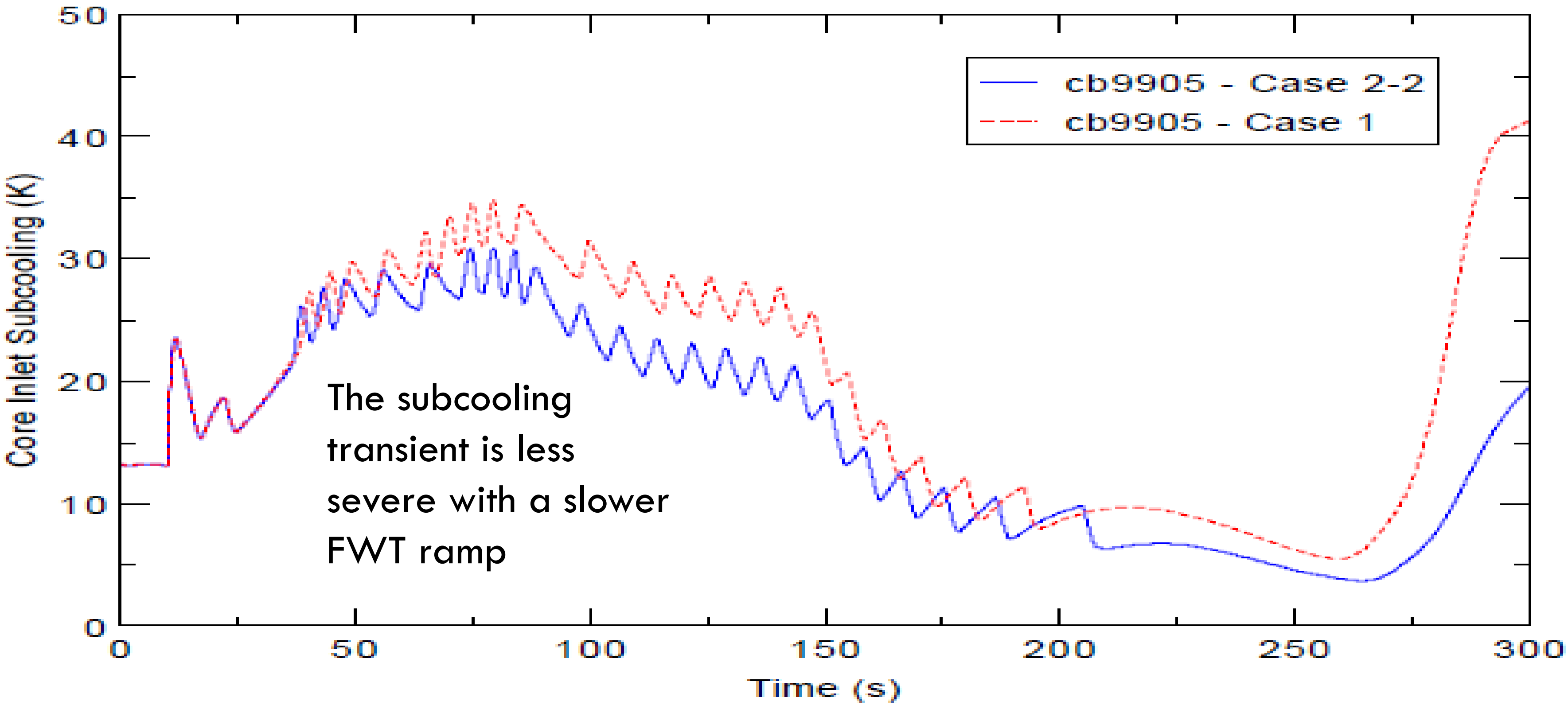
Evaluates sensitivity to rate of feedwater temperature decrease following isolation of extraction steam to the feedwater heater cascade.

Licensee performs analyses with a FWT ramp of -1.3 °F/sec (the original TRACG analysis rate) and a slower FWT ramp -0.5 °F/sec (the updated TRACG analysis rate).

EFFECT OF FEEDWATER TEMPERATURE TRANSIENT

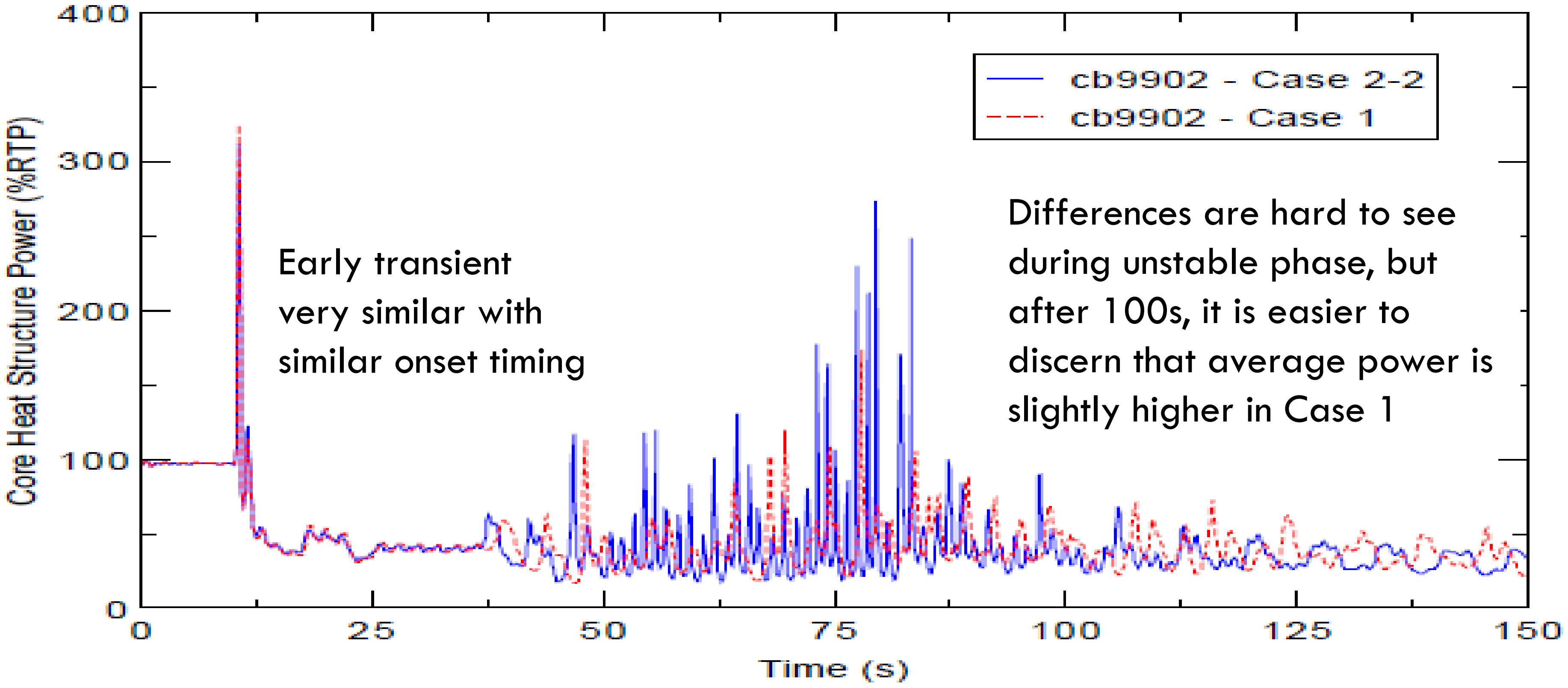


FWT AND SUBCOOLING



The subcooling transient is less severe with a slower FWT ramp

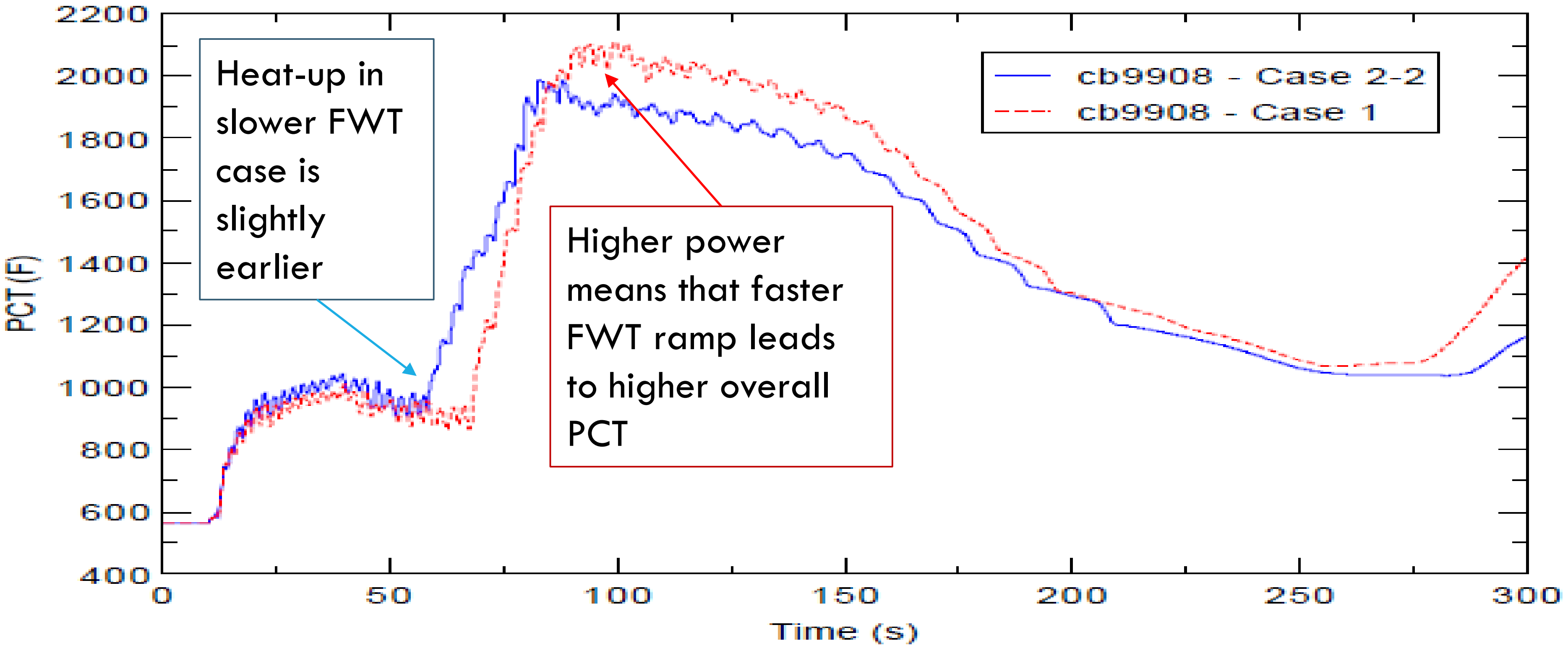
CORE POWER



Early transient very similar with similar onset timing

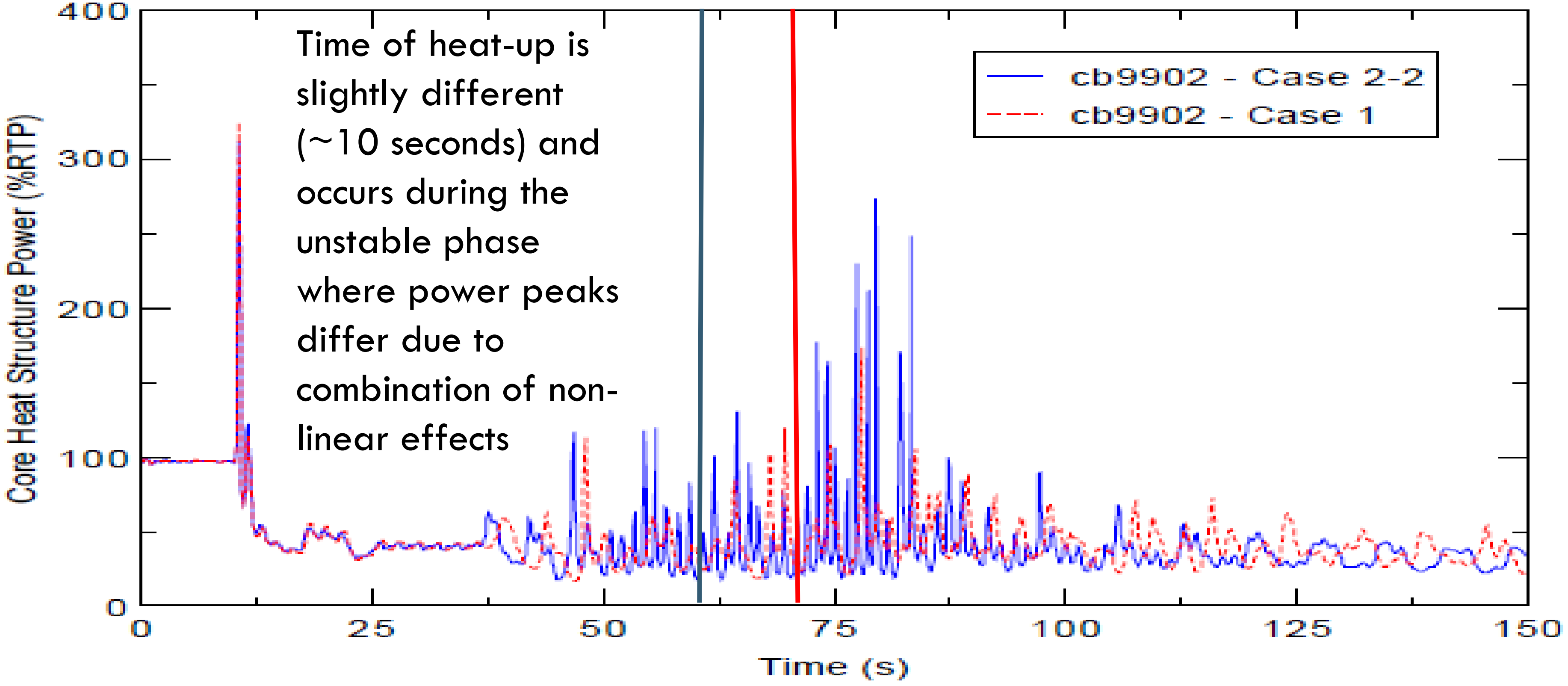
Differences are hard to see during unstable phase, but after 100s, it is easier to discern that average power is slightly higher in Case 1

CORE PCT



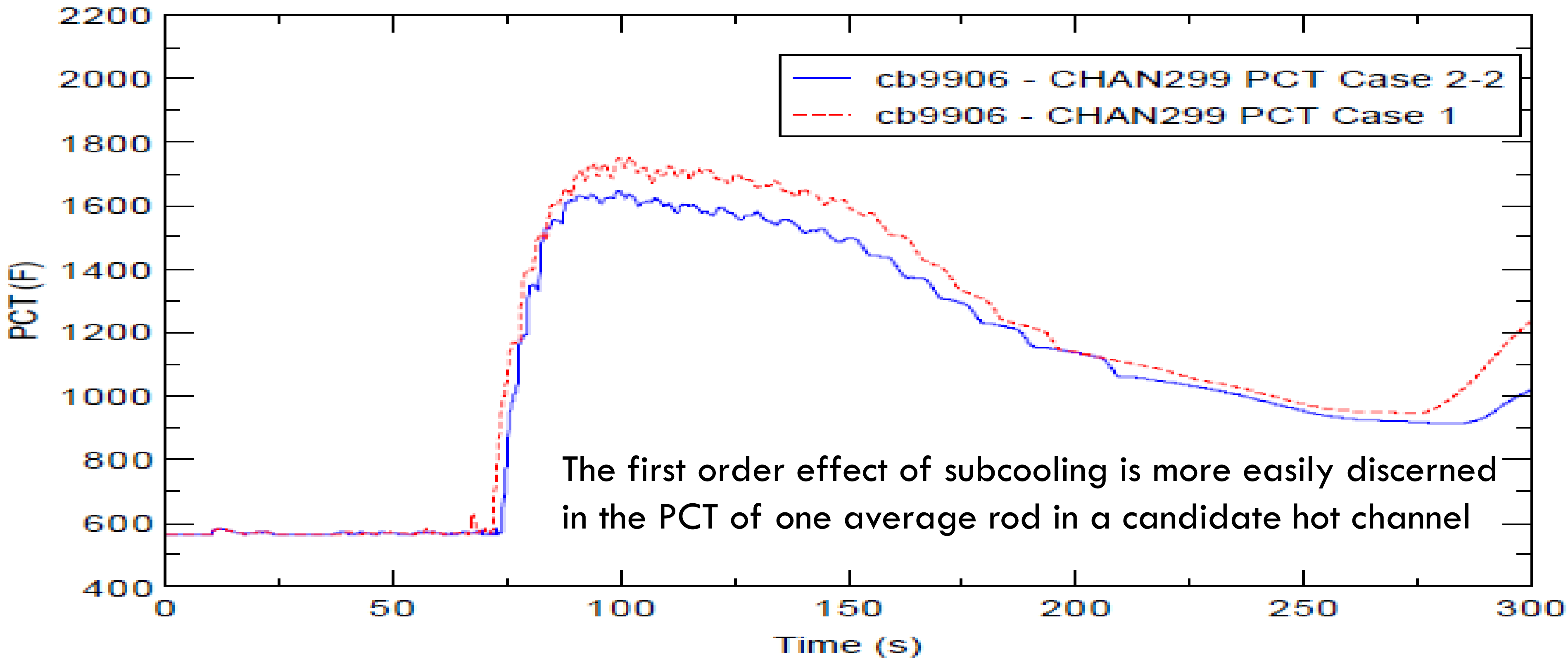
Heat-up in slower FWT case is slightly earlier
Higher power means that faster FWT ramp leads to higher overall PCT
cb9908 - Case 2-2
cb9908 - Case 1
PCT (F)
Time (s)
2200
2000
1800
1600
1400
1200
1000
800
600
400
0
50
100
150
200
250
300

CORE POWER



Time of heat-up is slightly different (~10 seconds) and occurs during the unstable phase where power peaks differ due to combination of non-linear effects
cb9902 - Case 2-2
cb9902 - Case 1
Core Heat Structure Power (%RTP)
Time (s)
0
100
200
300
400
0
25
50
75
100
125
150

PCT OF CANDIDATE HOT CHANNEL



HGAP SENSITIVITY FOR SLOW FWT RAMP

Case	T-Index	HGAP	PCT	Time of peak PCT	Time when PCT > 1200 °F
		kW/m^2-K	°F	sec	sec
2-2	1	3	1914	82	56
2-2	2	6	1822	96	71
2-2	3	9	1735	107	82
2-2	4	12	1988	83	64
2-2	5	15	1807	128	75
2-2	6	18	1888	121	73
2-2	7	21	1925	151	84
2-2	8	24	1845	107	75
2-2	9	27	1614	145	85
2-2	10	30	1560	139	84

CASE 2-1 DESCRIPTION

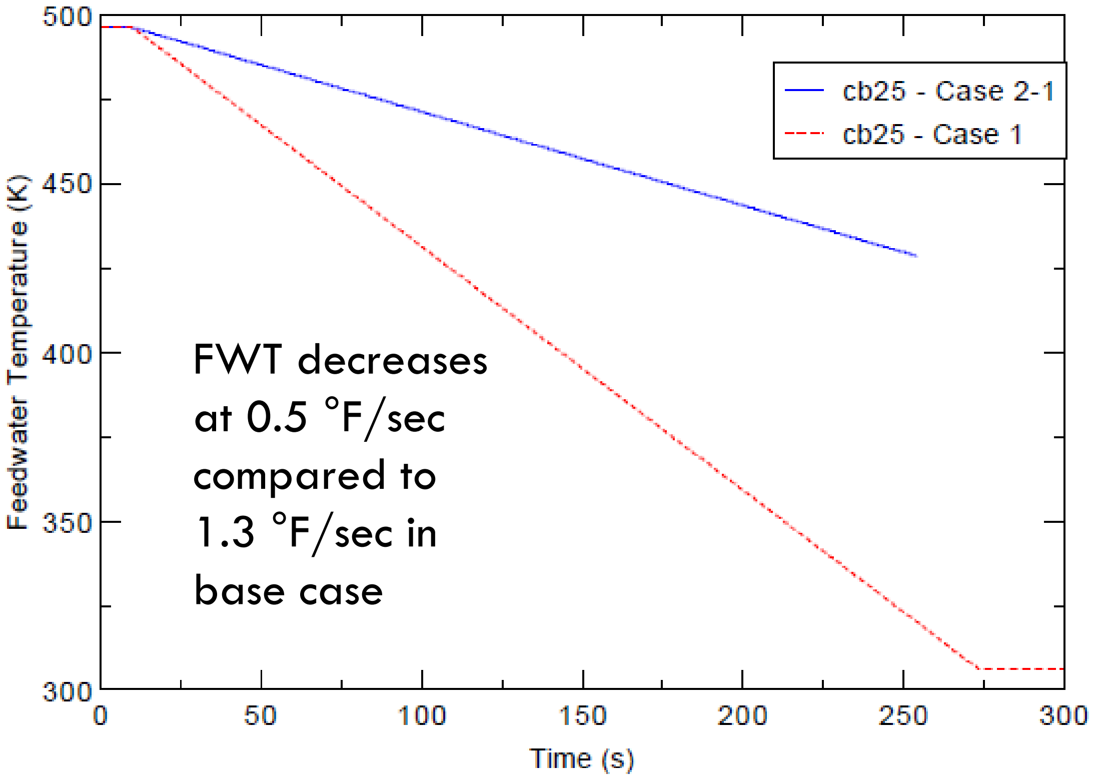
Evaluates sensitivity to manual operator action timing to reduce reactor water level.

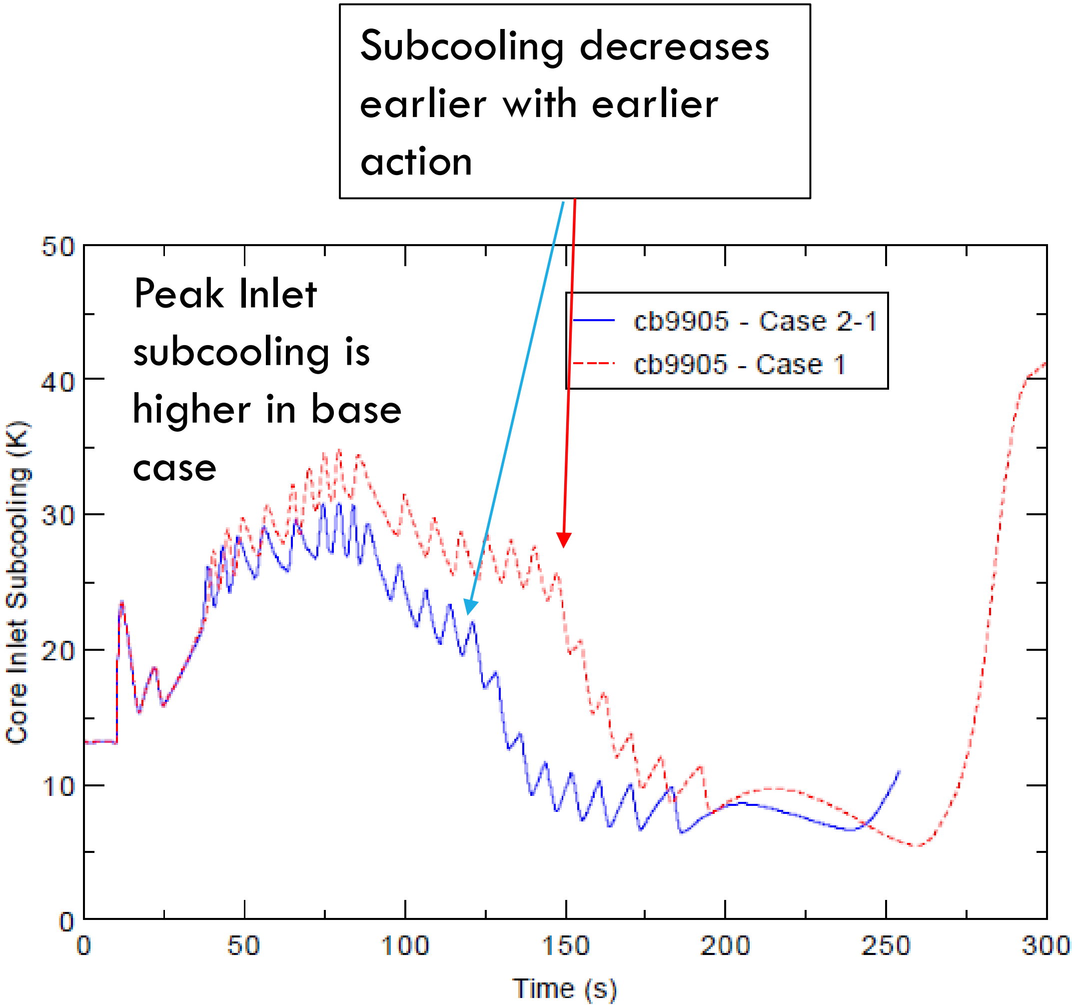
Licensee performed calculations assuming operators begin manual water level control at 120 seconds and 96 seconds.

96 seconds is 80 percent of 120 seconds and is used as a metric for operator training by the licensee.

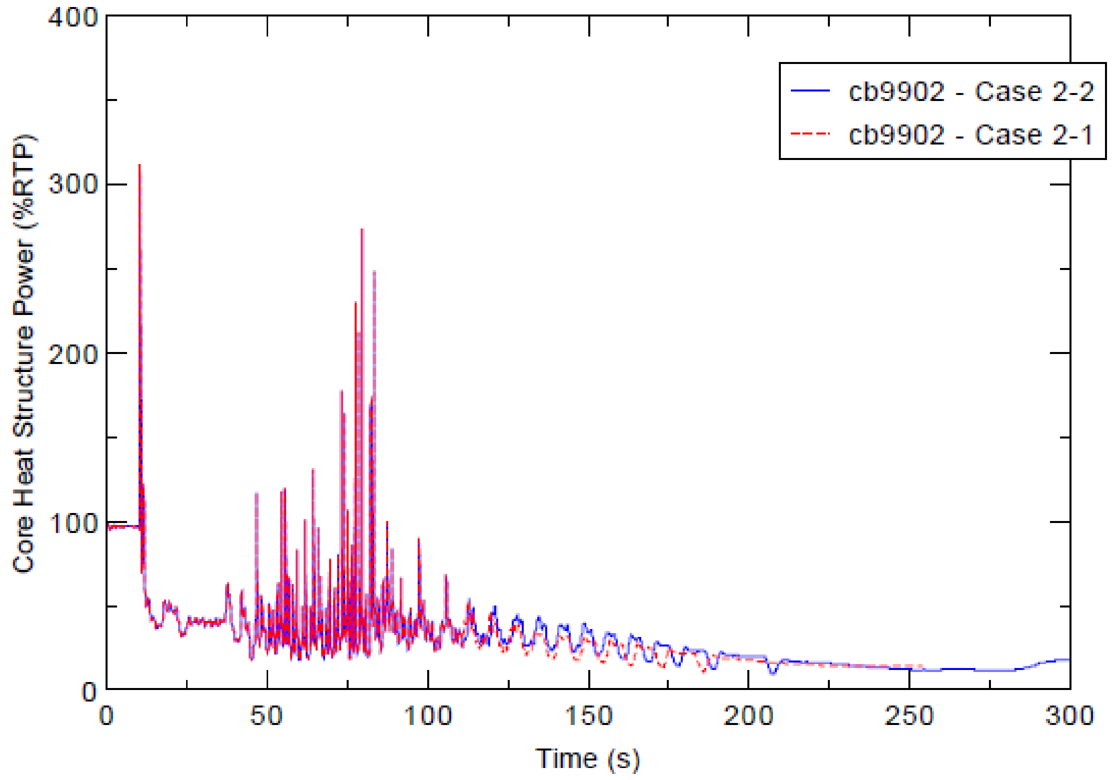
A FWT ramp rate of -0.5 °F/sec is assumed.

FWT AND SUBCOOLING





CORE POWER

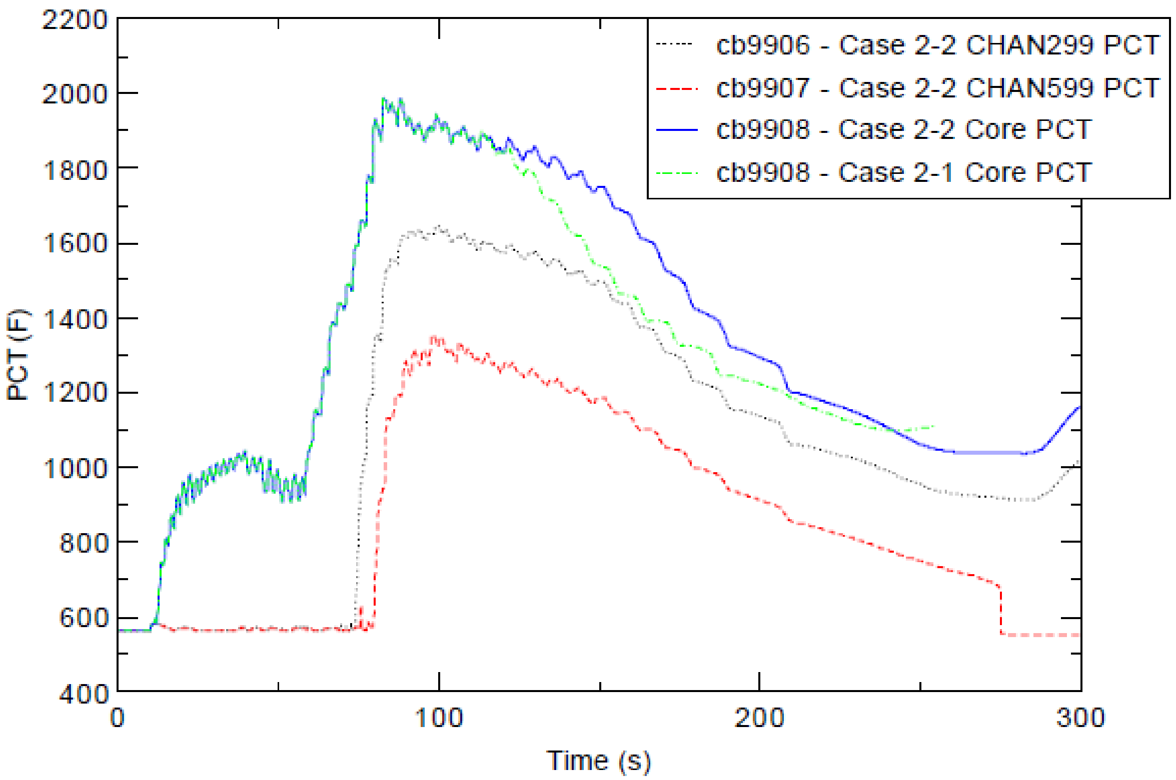


Core power response very similar in overall trends to base case and Case 2-1

Core power is lower owing to lower subcooling compared to the base case

Power decreases earlier because of earlier level reduction.

PCT



PCT is the same in Cases 2-1 and 2-2 because the PCT occurs ~80 seconds which is before the start of manual level control (106 seconds).

PCT is on a downward trajectory earlier when the operator action is earlier.

HGAP SENSITIVITY FOR EARLIER LEVEL CONTROL

Case	T-Index	HGAP	PCT	Time of peak PCT	Time when PCT > 1200 °F
		kW/m^2-K	°F	sec	sec
2-1	1	3	1914	82	56
2-1	2	6	1822	96	71
2-1	3	9	1745	114	82
2-1	4	12	1988	83	64
2-1	5	15	1787	113	75
2-1	6	18	1867	117	73
2-1	7	21	1840	125	84
2-1	8	24	1844	107	75
2-1	9	27	1573	121	85
2-1	10	30	1549	99	84

United States Nuclear Regulatory Commission

Protecting People and the Environment

CONCLUSIONS

Dr. Peter Yarsky
US NRC Office of Nuclear Regulatory Research

CONCLUSIONS

1. Of the three cases analyzed, Case 1 represents the worst combination of FW temperature response (-1.3 °F/sec) and manual operator action timing (120 seconds). The results of the analysis indicate that PCT remains slightly below 2200 °F for the worst HGAP analyzed. The PCT was 2109 °F.
2. Case 1 results confirm the effectiveness of manual operator actions (i.e., lowering level and injecting SLCS) to suppress the oscillations and bring the PCT on a downward trajectory.
3. In Case 1, the PCT was not very sensitive to HGAP with values ranging between ~1900 and ~2100 °F.

CONCLUSIONS

4. TRACE may under-predict condensation heat transfer once feed flow is restored and the feedwater injection is into the steam atmosphere above the liquid level in the downcomer. This under-prediction may be a result of the TRACE level tracking model. The level tracking model may under-predict the interfacial area available for condensation heat transfer. As a result, TRACE predicts an increase in core inlet subcooling that is larger than expected after feed flow is restored to maintain level. However, because the peak PCT has already been achieved, the TRACE calculation results in this phase do not impact conclusions with respect to PCT consequences.

CONCLUSIONS

5. TRACE predictions show higher than expected jet pump flow asymmetry in many of the runs following the restoration of feed flow (about 30 percent in some instances). The exact cause for this behavior is not fully understood at this point. The RES staff plans to conduct further analysis to fully understand it. However, because the peak PCT has already been achieved, the TRACE calculation results in this phase do not impact conclusions with respect to PCT consequences.

6. Cases 2-1 and 2-2 confirm that slower feedwater temperature reduction and earlier level reduction result in a lower PCT and a milder transient.

CONCLUSIONS

7. All cases indicate margin to fuel damage. Case 2-2 TRACE-predicted PCT agrees relatively well with reference results provided by the licensee. Case 2-1 shows a higher PCT than the reference TRACG result. In Case 2-1, TRACE predicts earlier instability onset that leads to heat-up, whereas TRACG does not predict significant power/flow instability.